STOCHASTIC MODELLING AS A DESIGN TECHNIQUE FOR PREDICTING INTERNAL HEAT GAINS IN BUILDINGS

by

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SUMMARY

Building internal heat gains from people, lighting and equipment have been identified as a source of uncertainty in estimating building heating and cooling loads and energy requirements. The common practice for estimating the internal heat gains relies on a single worst case design value which is usually assumed constant over the occupation period (constant profiles). In reality the building occupancy and the use of lighting and equipment are characterized by being partially time dependent and partially random. A preliminary study using simple variable profiles has shown that the consideration of the time variation of internal heat gains can lead to significant effects on the estimates of the heating and cooling loads and the total energy requirements when compared with the constant profiles. This study justified the development of more accurate methods of estimation of the internal heat gains.

One suitable approach for modelling the random variation of internal heat gains is the use of stochastic techniques. Hence a stochastic model has been developed using real-life data to predict the likely building occupancy patterns of office buildings and the likely use of the lighting and equipment in different time steps. Arrival and departure information for staff and visitors was collected from two large office buildings. Statistical analysis of this information provided the input data on occupancy for the stochastic model. Good agreement between predicted and observed patterns was obtained within the available data.

The lighting use has been related to the occupancy patterns, daylight levels and type of control. A stochastic model has been developed for predicting the use of manually controlled lighting for a probabilistic model described by BRE which was based on field studies of artificial lighting. Models were also developed for localised and photoelectric lighting control

The use of equipment has been predicted based on the simulated occupancy

patterns and the average probability of use. The model of equipment offers the possibility of simulating the use of equipment according to its function and type (personal or general).

The results of the predictions of internal heat gains for each time step of the day (the stochastic profiles) have been used as an input to Strathclyde University's building thermal modelling program ESP to predict the overall heating and cooling loads and the total energy requirements for a well defined building. The results were compared with those obtained from using the constant profiles. The summarized results have shown that the use of the constant profiles of internal heat gains leads to inaccurate estimation in the building total heating and cooling energy requirement. The difference depends on the type of light control and is in the range of 12 to 42%. Differences of this order may be important when the thermal modelling programs are being used to compare design alternatives.

The following chapters of the thesis are original work:

Chapters 2, 4 and 6

The model described in Chapter 5 has been developed from field studies carried out by Building Research Establishment.

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DEFINITIONS

Definitions of some of the important terms used throughout the thesis are given below:

Dynamic Model: A method of predicting the magnitude, duration and time of occurance of each of a series of events.

Stochastic Process: A family of random variables which is dependent on the time t (or other parameters) within a defined time period T.

Stochastic Model: A method of predicting the magnitude, duration and time of occurance of each of a series of events using a stochastic process.

Simple Constant Profile: A rectangular profile for the magnitude of a variable over a period of time where the magnitude can be either zero or a fixed positive value.

Simple Variable Profile: A profile for the magnitude of a variable over a period of time where the magnitude can be zero or any positive value.

Stochastic Profile: A profile for the magnitude of a variable over a period of time where the magnitude can be zero or any positive value and has been produced by a stochastic model.

1. INTRODUCTION AND OBJECTIVES

Assessments of building energy requirements have up till now usually relied on a simple estimation of the heat emission from the internal heat sources. This simple method assumes that the heat emission from people, lighting and equipment has a constant maximum value during the occupation period. It is probable that this crude assumption leads to inaccurate estimations of building energy requirements when heating and cooling loads are evaluated. A preliminary study using simple variable profiles showed that the consideration of the variation of heat emission with time had a significant effect on the heating and cooling energy requirements. This justified the investigation of more accurate models of internal heat gains. The immediate objectives of this work were to develop models for:

(1) Prediction of building occupancy patterns taking into account the random variation from one day to another and based on real life data.

(2) Prediction of artifical lighting use in relation to occupancy, daylight level, and type of control.

(3) Prediction of equipment use in relation to occupancy.

These will enable better prediction of the heat emitted from each of the above components to give better evaluation of heating and cooling loads and hence to improve estimation of the building energy requirements which is the ultimate objective of this study.

1.1.1 Literature Review

Traditionaly, building and HVAC (Heating, Ventilating and Air Conditioning) system designers have relied on manual calculations of energy consumption as a basis of performance assessment at the design stage. These, in most cases, are based on empirical simplifications and steady-state calculations which were originally intended for estimating heating and cooling loads.

Clark [1.1.1] and [1.1.2] has traced three generations of models for energy consumption. The first generation were the traditional design methods set out in handbooks as explained above and extended to make crude estimates of building energy consumption. An example is the degree-day method which is based on steady-state calculations, but modified to account for thermal storage effects by simple correction factors for light, medium and heavy weight buildings. None of these models represents energy flow paths explicitly. In the mid 1970's, the need to model the dynamic effects of stored energy and internal conditions over short time scales gave rise to the second generation. These models calculate heat flows at a series of time steps but were mainly concerned with climatic-fabric interaction. The treatment of plant and controls was often non-existant and at best rudimentary. Convective and radiative heat flow paths were often combined using fixed surface heat transfer coefficients. The limitations of these models gave rise, in the early 1980's, to the third generation. These models treat building, plant and controls as a total energy system. No single energy transfer process is solved independently; at each time step a solution is found for all unknown variables by solving a set of equations for the entire system. ESP is an example of this type of dynamic thermal model.

The increasing use of models has led to an increasing number of validation studies. Cockcroft [1.1.3] has proposed the requirements for validation of a model and the techniques which can be used. He indicates that comparison with measurements (eg. heat flows) is important to evaluate predictions. The extent to which such models can be relied upon will depend on the extent to which they have been validated against a range of real buildings.

A methodology for validation of dynamic thermal models of buildings has been proposed by Bowman and Lomas [1.1.4]. Three techniques have been described, (1) analytical verification (the comparison of model prediction with carefully designed problems of known analytical solutions), (2) intermodel comparisons (predictions by two or more models of the thermal performance of some hypothetical building are compared), and (3) empirical validation (comparison of the predictions of the model with physical reality). Their relative merits were assessed by reference to previous validation work on ESP, SERI-RES, DEROB, and BLAST. The study has shown that numerous sources of error existed in previous studies leading to uncertainty in model predictions. Irving [1.1.5] has indicated that previous validation approaches suffer severe limitations. An integral part of the validation of thermal models is to perform a sensitivity analysis where several of the input values are adjusted and the induced change in the output values are used to deduce the response function between input and output. A stochastic sensitivity analysis technique was developed which appears to overcome the deficiencies and limitations of previous approaches and was used to perform a sensitivity analysis on the ESP thermal model.

One major validation exercise was organized by the International Energy Agency (IEA) [1.1.6]. The first stage was an intermodel comparison of 19 different models from 9 countries. The aim was to assess the reliability of these thermal models. Significant differences were found between the results from various models but it was difficult to identify explicitly those techniques which generated the most realistic modelling of buildings because there were no physical measurements for comparison. It was decided to undertake comparison with real building perfomance to resolve these differences. The Avonbank office in Bristol and the Collins building in Glasgow were therefore investigated by the Building Services Research Unit of Glasgow University [1.1.7]. These studies have influenced the way data is measured and the presentation of information. The modelling of air infiltration, fresh air supply, zone air coupling, thermal storage, and the magnitude and the convective/radiant proportions of internal heat sources were identified as sources of uncertainty which led to differences between predictions and measurements.

A study has been started recently (1988) [1.1.8] at Oxford University using dynamic thermal models of buildings for the comparison of different schemes of energy management. These workers are looking for models of internal heat gains to provide realaistic inputs to the thermal models.

From the validation studies, a general lesson could be deduced that any new additional features should be well tested before being introduced to the larger models. Internal heat sources are very dependent on the building occupancy. Identification of the occupancy patterns (taking into consideration the daily and seasonal variations) will help to identify the use of artificial lighting and equipment. The heat emission from the three sources could then be evaluated.

Dean and Ratzenberger [1.1.9] used a stochastic model of insolation, fabric heat transfer and internal heat gains to compare two designs for a variable air volume air conditioning system. This simulation enabled the comparison to be based on 'running' as opposed to 'design' conditions. The treatment of the internal heat gains in this model was very crude in that the total load from this component was taken as a percentage of its maximum design value. Details of the heat emission from each internal source (people, lighting and equipment) were not given and there was no mention of latent heat gain or of the convective/radiative splits of the sensible heat gain. The daily and seasonal patterns for the heat gain from each source were also absent. This model appeared to be specific to a certain design problem and cannot be used as a general guide for estimating building internal heat gains. The importance of each of the three components of internal heat gain and the relation between the building occupants and the use of lighting and equipment have been stressed in several studies. Wagner [1.1.10] has indicated that the nonavailability of accurate and sufficiently complete input data, especially on occupant behaviour limits the ability of even detailed models to accurately predict energy use.

Pecok [1.1.11] suggested that a more realistic estimation of building occupancy requires a technique which embodies the inherent randomness of arrival and departure times of occupants. The inference drawn from Wagner and Pecock is that there has been no attempt to model building occupancy patterns. Also, the shortage of information on this aspect would limit the ability of the models to accurately predict energy use. One of the main reasons behind this is the requirement of detailed real-life data to cover the daily and seasonal variations.

The heat gain from high levels of artificial illuminance was reviewed by Roberts in 1963 [1.1.12] with particular reference to conditions in USA. Bedocs [1.1.13] has assessed the developments which have taken place in the UK during the ensuing seven years (1963-1970). He has stressed the need for the integration of lighting with heating, ventilating and air conditioning. Several studies have been carried out by the Building Research Establishment (BRE) to discover how people use artificial lighting. A method has been presented by Hunt [1.1.14] for predicting the likely use of manually operated lighting. In this method the probability of switching the lighting on was established from observed behaviour in relation to the daylight and by assuming that the occupation period was constant during the year. The method was required mainly to estimate the annual average number of hours that the lighting was used to estimate the annual energy consumed. Simulation of lighting use for individual days (taking into consideration the random variation in the building occupancy and the actual daylight) did not appear in the BRE studies. Estimation of the heat emission according to lighting use and type of control was also absent because these studies were intended to reduce the use of artificial lighting by introducing suitable lighting controls.

The use of building equipment has not been covered as widely as lighting. The reasons are, firstly, that the equipment is not the major component of power consumption and,secondly, the modelling of equipment needs to be related to the building occupants. A study was carried out by Howard [1.1.15] to predict the maximum heat gain arising in microbiological research laboratories for the purpose of designing an air conditioning system. The study revealed that the actual heat gain from equipment was quite variable and regularly fell to 50 or 60% of the maximum use. However, a general strategy for predicting the use of different equipment according to its type and function was not developed in this study since the objective was to solve the design problem of plant sizing. Summarizing, an accurate evaluation of the building internal heat gains appears to be important in evaluating accurately building heating and cooling loads and energy requirements. Building occupancy patterns have not been modelled from the heat emission point of view. Lighting use was aimed at the average annual use, and the equipment use was restricted to a specific design problem. Stochastic modelling of each of the three components offers the possibility of more realistic models.

1.1.2 Stochastic Applications in Related Areas

Stochastic modelling has been increasingly used in some related areas with the aid of computer simulation. Brinkworth [1.1.16] has shown that the sequential characteristics of the daily insolation can be represented in simple numerical terms derived from an autocorrelation function of a straightforward stochastic model. Synthetic sequences can be generated which match the long-term characteristics of the insolation with respect to its sequential properties, as well as to the seasonal trend and the variance of the fluctuations.

In his presentation of a short-term stochastic model of internal and external air temperature for an occupied residence, Loveday [1.1.17] has indicated that deterministic thermal modelling of a building is usually applied at the design stage for estimating internal temperatures during use. Once the house is built and occupied, stochastic modelling of such temperatures becomes possible, inclusive of the random and sequential variation in climate and occupancy patterns. Auto correlation coefficients were also presented for a time series of the external and internal dry bulb temperatures relating to an occupied residence.

Irving [1.1.5], Dean and Ratzenberger [1.1.9] have introduced stochastic models as discussed in Section 1.1.1.

1.2 BUILDING INTERNAL HEAT GAINS

Internal heat gain is defined as the heat emitted from heat sources within an internal space mainly from occupants, lighting, electrical motors, electronic equipment, kitchen equipment and miscellaneous appliances etc., in the form of sensible and latent heat. The sensible heat is the dry heat emitted from the sources to the environment by means of conduction, convection or radiation, the proportion depends on the type of heat source used and this will be discussed below. The radiant portion of the sensible heat emitted from internal sources is partially absorbed in the building structure and furnishings and contributes to the space cooling load only after a time lag, hence reducing the instantaneous heat gain. The latent heat gain is the rate of enthalpy increase due to the addition of moisture to the space. The main sources of the internal heat gain are discussed below.

1.2.1 Occupants

Human beings give off sensible and latent heat at a metabolic rate which is dependant on their rate of activity, mode of dress and the environmental conditions (air temperature, air movement and humidity). The total latent heat gain caused by human beings is divided into respired vapour loss and evaporative heat loss from the skin. The skin evaporative heat loss varies between two levels. Firstly, the minimum value for a given environment is set by evaporation of water diffusion through the outer layer of the epidermis. Secondly, the maximum value occurs when the entire skin surface is 100% wet from regulatory sweating. The total latent heat gain can be considered as instantanaeous cooling load [1.2.1] while the total sensible heat gain is not converted directly to cooling load; the radiant portion, as mentioned earlier, is first absorbed by the surroundings, then converted to the room at a later time depending on the thermal characteristics of the room. Jones [1.2.2] indicated that deciding on density of occupation is usually a problem for the air conditioning designer. A normal density for an office block is $10m^2$ per person as an average over the whole conditioned floor area. The density of occupation may be as low as $20m^2$ per person in executive offices or as high as $6m^2$ per person in open office areas. Some premises may have much higher densities than this. For restaurants $2m^2$ per person may be reasonable, but for department stores at certain times of the year, densities may reach values of 1.5 to 1.0 m^2 per person, even when allowances have been made for the space occupied by goods. In concert halls, cinemas and theatres, the seating arrangement provides the necessary information but in dance halls and night clubs, estimates are open to conjecture.

1.2.2 Lighting

The major component of heat gain in the interior zones of modern buildings is the power supplied to the lighting. Electrical lighting is usually chosen to produce a certain standard of illumination and, in doing so, electrical energy used by a lamp is ultimately released as heat. Some of the energy emanating from lights is in the form of radiation that only affects the air after it has been absosrbed by walls, floors and furniture. This stored energy contributes to the space cooling load after a time lag which should be taken into account when calculating the cooling load [1.2.1]. The total electrical power input to the lighting installation has to be known. For lamps which have associated control gear, it is important to add the power dissipated by the control gear to that dissipated by the lamp.

The standard of illumination produced depends not only on the electrical power of the source but also on the method of light production, the area of the surfaces within the room, their colour and their reflection properties. The consequence is that no straightforward relationship exists between electrical power and the standard of illumination. Storage factors have been published [1.2.3] for exposed and recessed light fixtures, but there is nothing in the literature to support this data. Several studies, both experimental and analytical [1.2.4], [1.2.5] and [1.2.6] have indicated the effect on the cooling load of light fixture type, type of air supply and return, space furnishings and thermal characteristics of the space. Mitalas [1.2.5] formulated these parameters into a set of numerical values permitting calculation of an appropriate cooling load factor (CLF). Where luminairs are recessed into the ventilated ceiling or are used as an air outlet, for the extraction of air from the room, the heat transmitted to the room will be reduced below the normal rating of the lamp. Heat which is taken away from a luminair via a ceiling plenum or directly from the luminair itself will not form part of the room sensible heat gain, but will still constitute a part of the total refrigeration load.

With increasing levels of light the amount of radiation heat generated by an installation will also increase. This heat which is difficult to control, even by the use of air conditioning, can lead to complaints by occupants [1.2.7].

1.2.3 General Appliances and Office Equipment

The most common heat-producing appliances found in conditioned areas are those used for food preparation in commercial and industrial food service establishments such as restaurants, hospitals, schools, hotels, etc. Counter and back-bar appliances are frequently located in the dining or serving area, while heavy-duty equipment is usually confined to the kitchen and installed under an exhaust hood. A laboratory test [1.2.8] showed that convective and latent heat were negligible when appliances were installed under an effective hood, while they should be considered for unhooded appliances. Due to the frequent absence of manufacturer's data of the heat released from these appliances, it has been common practice to introduce usage factors [1.2.1] that, when multiplied by the input rating approximates the actual hourly input to the appliances.

For computer and office equipment, it was found that the heat dissipated by similar types of electronic equipment varied considerably from one manufacturer to another [1.2.7]. An indication of the typical heat dissipation rate per m^2 of floor area for rooms containing different types of electronic data-processing equipment is usually found in tables, which are mainly used for assessing loads during the preliminary design stage and in the absence of manufacturer's data.

1.3 OUTLINE OF PROJECT

The whole scope of this study can be summarized in seven stages.

The First Stage: " Preliminary Analysis "

Initially no information was available about the effect of the time variation of the heat emission from people, lighting and equipment on a building's total energy requirement. Hence it was important to have an indication of this effect and its significance when comparing it with the simple constant profiles commonly assumed for each source of the building internal heat gains.

Simple variable profiles against the constant profiles of internal heat gains were compared in two office buildings. The ESP program was used to predict the buildings' energy requirements for different weeks. The results indicated that a significant difference existed when time variations of the internal heat gains were considered. This confirmed that it was worthwhile to continue with the next stages of this study.

The Second Stage; " Data Collection and Problems"

The original intention of this study was to establish a computer model to simulate occupancy patterns in different types of buildings for the purpose explained in Section 1.

It was expected that the most accurate information and data required to establish the model would be found in commercial and industrial establishments. Flexi-time systems (controlled by computer) offered the possibility of accurate recordings of the times of arrival and departure of the occupants throughout the working day. The first step was to identify the names and locations of these establishments and then to seek information about staff and visitors arrival and departure times, lunch and coffee breaks, times when lighting and equipment was switched on and off and type of building.

Although we contacted a number of these establishments, the information and data obtained were only for the following two office buildings:

(a) The Scottish Mutual Assurance Society (400 persons), located in Glasgow city centre. The data obtained was a daily computer listing of the staff arrival and departure times and a manual record for the visitors.

(b) The South of Scotland Electricity Board (a complex of three buildings, 724 persons). The data was obtained for building staff only. Visitor data was not obtained due to security problems.

As was expected, accurate and reliable information about lighting and equipment above was not available, so that a different approach was adopted.

The reasons behind the difficulties to gather the same information about buildings other in an offices are essentially due to (1) security problems, (2) visitors movement was mixed with staff and both were not recorded or (3) the data was thrown out after payment, assessment etc. All these difficulties have restricted the data collection to the two offices mentioned earlier.

The Third Stage: "Data Processing and Analysis"

The decision about the size and the period of time required for the data collection was not a straightforward process. A preliminary study of some samples of data collected from the first office building enabled a decision to be made. The collected data was processed and modifications made for missing and odd records. Different statistical analyses were performed and by using the results of these analyses, the model of occupancy patterns has been developed.

The Fourth Stage: " Prediction of Building Occupancy Patterns "

Having collected all the required data about the building staff and vistors, the data for each was handled separately. Simulation of building staff was performed first to assess the number of staff occupying the zone at each time step, the smallest interval being five minutes. Then vistors' patterns were simulated for each zone using a different technique. The number of visitors in the zone was assessed also at each time step. The total number of people in the zone in each time step was calculated simply by adding the number of staff to the number of visitors (if there were any). The actual heat emission from the occupancts of the zone was then calculated.

The Fifth Stage: " Prediction of Artificial Lighting Use Related to Occupanacy Patterns and Daylight Level "

The model of the lighting use in any zone of the building was based on Building Research Establishment research in this field, but modified to stochastic simulation of lighting use related to the daylight, occupancy patterns, and types of control. The model was constructed to consider mainly three types of controls: (1) manual control (2) localized control (3) photoelectric control (on/off, dimming and multi-control (on/off and dimming)).

The model predicts the lighting use in a zone controlled by manual or localized switching related to daylight level, so that the total actual lighting use in each time step is defined and the total heat emission calculated.

The Sixth Stage: " Prediction of Equipment Use Related to Occupancy Patterns "

The last stage of the model construction was the simulation of the zone equipment use related to the occupancy patterns. In the model of equipment use it was considered that the use of each piece of equipment is random throughout the working day and is based on the average probability of use. Three cases were considered in terms of equipment type and function: (1) Zone equipped with personal use equipment (e.g. typewriter, word processors, etc) (2) Zone equipped with general use equipment (e.g. photocopier, VDU terminals, etc)

(3) Zone equipped with both personal use and general use equipment (1+2).

For any zone the model simulates the use and the heat emitted from each piece of equipment in each time step. The total equipment heat emission is therefore calculated in each time step.

The Seventh Stage: " Building Energy Requirement Analysis "

Throughout the previous stages, the stochastic model required to simulate the building internal casual gains from people, lighting, and equipment was completed. The model output was arranged to fulfil the requirements of the ESP program (The UK Strathclyde Building Energy Simulation program), where for each simulation time step, the total sensible convective, sensible radiant and latent heat gains (all in watts) for the zone were supplied. Predictions of building energy requirements using stochasticly modelled building internal heat gains and the simple constant profiles were compared and discussed with the help of figures and tables.

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2 *PRELIMINARY ANALYSIS*

2.1 OBJECTIVES OF THIS ANALYSIS

The objectives of this preliminary analysis are as follows:

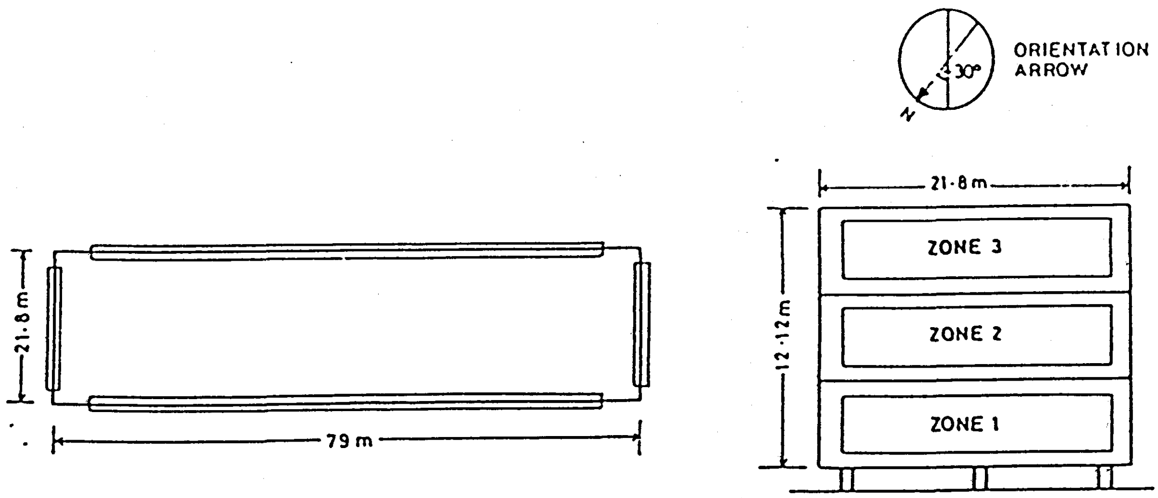
(1) To compare two different occupancy profiles of internal heat gain, one which represents the simple constant profile commonly used, and the other is a simple variable profile representing the variation of internal heat gains with the time mainly during morning arrival and afternoon departure periods.

(2) To investigate if the consideration of this variation leads to significant differences in the estimation of building energy requirements when compared with the simple constant profile.

(3) To decide therefore if a comprehensive study towards accurate estimation of the time variation of internal heat gains is worthwhile.

2.2 PREDICTION OF BUILDING ENERGY REQUIREMENTS

A building energy analysis was carried out on a hypothetical three floor office building (the IEA-O) building) which is typical of commercial building construction in many parts of the United States and Europe. This building was chosen for this analysis because it was well documented and has been used before for differenet thermal analyses. The building thermal characteristics, and the sources of internal heat gain are described in reference [1.1.6]. Each floor constitutes a single uniform zone. The building is shown in Fig 2.1 and the sources of internal heat gain are listed in Table 2.1 with their peak values and the convective/radiative splits. All zones are considered to be controlled at (23°) in winter and (24°) in summer when the building is occupied. These indoor temperatures are maintained by imaginary heating and cooling systems distributed uniformly in space. The heating system was assumed to generate heat to offset the transient heat loss through the building fabric and structure



A ZONE PLAN

SIDE VIEW

FIGURE 2.1 THE LARGE OFFICE BUILDING (IEA-0)

TABLE 2.1

Sources of Internal Heat Gains of the Large Office Building

Zone No.	People No.	People heat emission / watts		Peak light'g watts	Peak equip't watts	Connective Radiative Splits					
						People		Lighting		Equipment	
		Sensible	Latent			con	rad	con	rad	con	rad
1	170	16150	7650	58087	60000	0.8	0.2	0.5	0.5	0.6	0.4
2	170	16150	7650	58087	60000	0.8	0.2	0.5	0.5	0.6	0.4
3	170	16150	7650	58087	60000	0.8	0.2	0.5	0.5	0.6	0.4

and to maintain the space at design condition (23°). The cooling system was assumed to absorb heat to offset transmission and solar gains through walls and windows, and the internal heat gains to maintain the space at design conditions (23°). Hence the heating and cooling loads of the space were evaluated, and the building energy requirements were estimated. A preheating or cooling of two hours before the occupation period was assumed within the building control strategy, and the building was assumed to be occupied from Monday to Friday. Another office building (a smaller one) of a single floor containing three zones was also examined. Office construction, geometry, and the internal heat sources were designed by the Architectural Department of Strathclyde University. The office plan is shown in Figure 2.2 and the sources of internal heat gain are listed in Table 2.2 with their maximum values and the convective/radiative splits. The building control strategy was exactly the same as for the large office building. These two office buildings, differing in size and amount of internal heat gain, were selected for this analysis to allow a check to be made for consistency.

ESP (Energy Simulation Progam) was used to estimate heating and cooling energy requirements in both buildings and was based on an hourly time step. Three simulation periods were selected for this analysis: the winter week (11-15 December), the summer week (19-23 June) and the autumn week (9-13 October). The typical U. K. climate data (Kew 1967, south of England) which is available within ESP was used.

An energy prediction was started for the large office building where the simple constant profiles shown in Figure 2.3 were used. These profiles were altered to more realistic (but still simple) profiles by considering spread of people arriving and departing over a period of time during the morning arrival and the afternoon departure periods. These represent in a simple manner the case of a building running a flexi-time system.

Due to the absence of actual data representing the usage of lighting and equipment, these were assumed to be approximately proportional to the variation

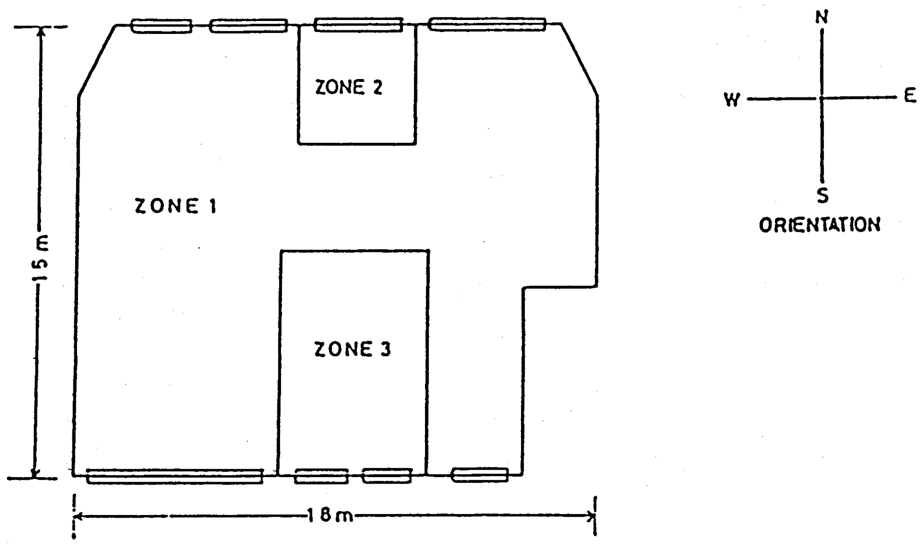
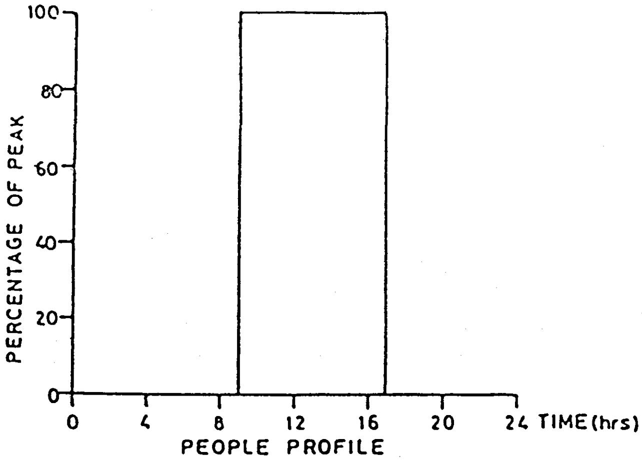


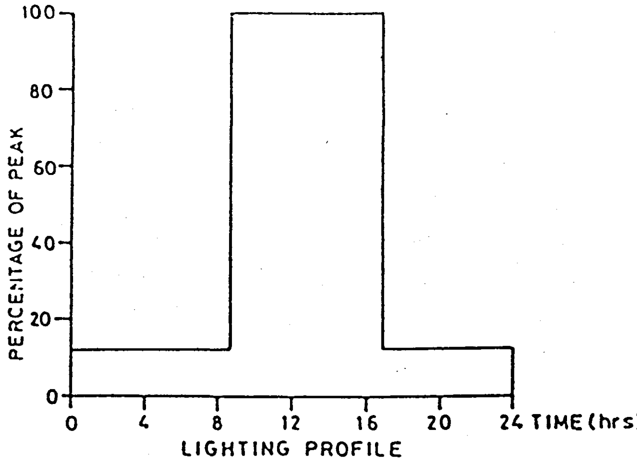
FIGURE 2.2 THE SMALL OFFICE BUILDING

TABLE 2.2

Sources of Internal Heat Gains of the Small Office Building

Zone No.	People No.	People heat emmission / watts		Peak light'g /watts	Peak equip't /watts	Connective Radiative Splits					
						People		Lighting		Equipment	
		Sensible	Latent			con	rad	con	rad	con	rad
1	34	3298	1562	5000	139	0.8	0.2	0.4	0.6	0.2	0.8
2	2	191	90	289	8	0.8	0.2	0.4	0.6	0.2	0.8
3	5	544	241	744	22	0.8	0.2	0.4	0.6	0.2	0.8





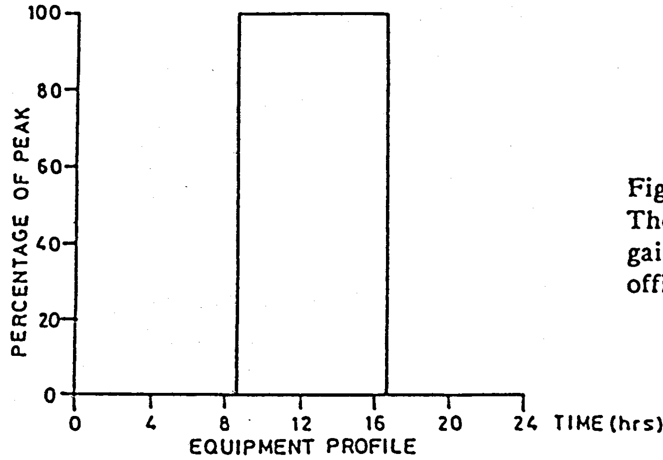
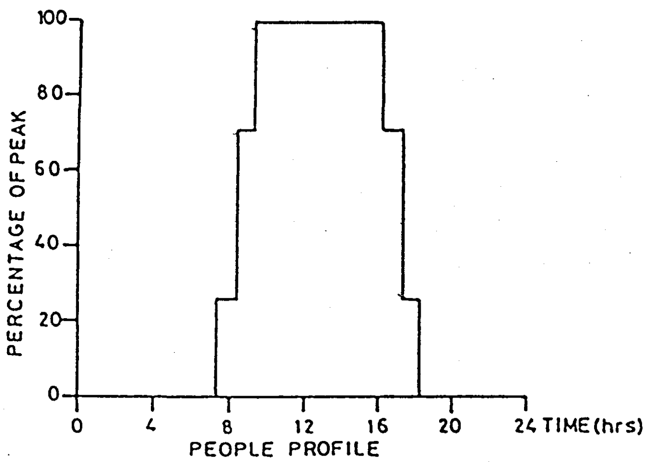
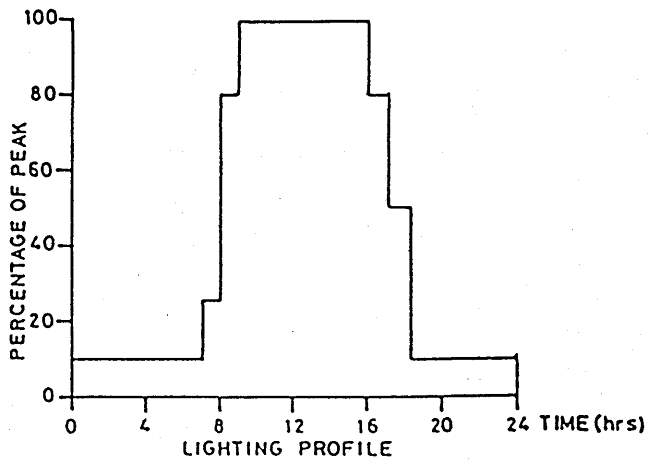


Figure 2.3
The constant internal heat gain profiles of the large office building (9–17) hours





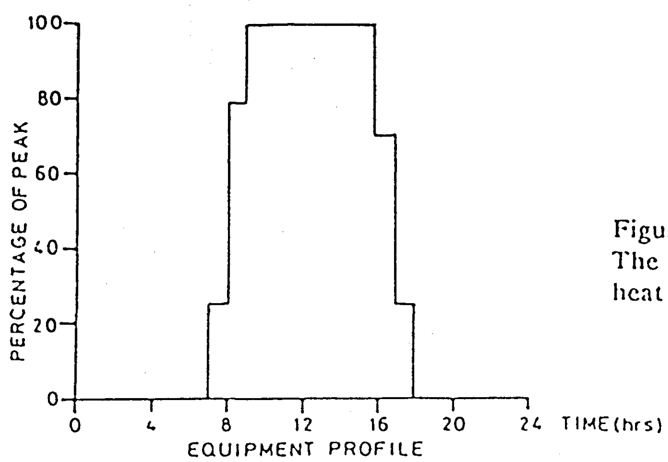


Figure 2.4
The altered (flexible) internal heat gain profiles (7–18) hours

in the numbers of people. These simple variable profiles are shown in Figure 2.4 and will be called the flexible profiles in the rest of the chapter. Building energy predictions were also carried out using these profiles and the results of both profiles are listed in Table 2.3. Energy predictions for the small office building during the same weeks have also been carried out. The constant and altered (flexible) profiles of the internal heat gains were used respectively. See Figures 2.5 and 2.6. Results of the building energy requirements of both profiles are listed in Table 2.4.

It is worth mentioning that for the large office building the area of the altered (flexible) profile of each component is larger than the area of the constant profile of the same component by approximately 11%. See Figures 2.3 and 2.4. This implies that the number of man-hours worked has increased by 11% because flexible working hours had been introduced. This is unlikely to be realistic. Energy predictions were therefore investigated for the large office building with equal areas for the constant and flexible profiles (i.e equal area means that the total energy emitted from each source is equal in both constant and flexible profiles). The constant profiles are the same as shown in Figure 2.3, while the altered (flexible) equal area profiles are shown in Figure 2.7. Results of building energy predictions of this case are listed in Table 2.5.

So far, two cases to be compared were introduced. The first case was when the areas of the constant and flexible profiles were different (i.e. the occupation period and the energy emitted from each source were not equal). The second case was when the areas of constant and flexible profiles were equal (i.e. the energy emitted from each source was equal, but the occupation periods still different). Since for each case two hours of pre-heating before the occupation period was adopted, the number of heating or cooling hours of flexible profiles is higher than the constant profiles (i.e. two hours more in the early morning and one hour more in the late afternoon). See Figures 2.3 and 2.4. We would expect then a clear difference in the total building energy requirements. Therefore it is important to investigate the case when the occupation period and

TABLE 2.3

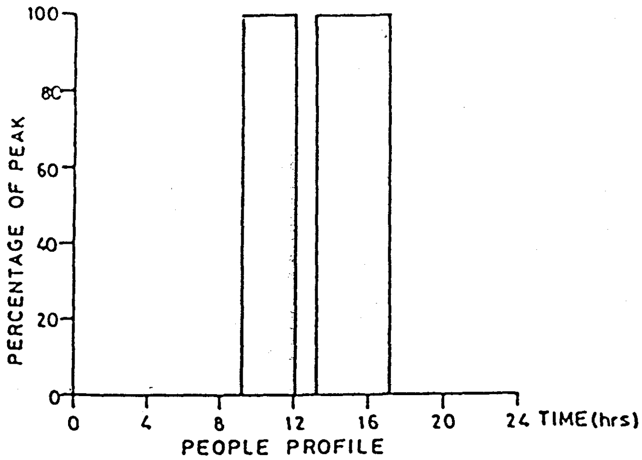
Loads and Energy Requirements of the Large Office Building When the Constant and Altered (flexible) Profiles Shown in Figures (2.3) and (2.4) were used.

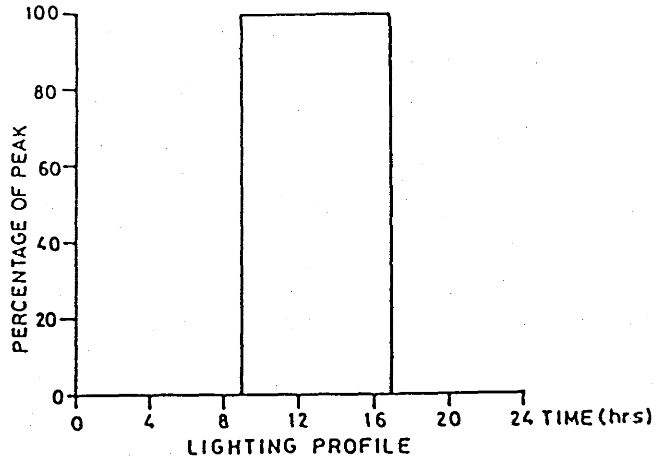
Simulation Period	Sources of Heat	Constant Profiles Fig 2.3				Altered (flex.) Profiles Fig 2.4			
		Max Load /Kw		Energy /Kwhrs		Max Load /Kw		Energy /Kwhrs	
		Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g
11-15 Dec	All	329.9	-101.0	2926.0	-1429	355.6	-127.0	3981.6	-2006.2
19-23 June	All	41.3	-351.4	88.8	-10782	87.0	-354.6	450.5	-12615.2
9-13 Oct	All	114.5	-225.2	703.5	-6676	117.9	-247.2	1045.9	-7640.0

TABLE 2.4

Loads and Energy Requirements of the Small Office Building When the Constant and Altered (flexible) Profiles Shown in Figures (2.5) and (2.6) were used.

Simulation Period	Sources of Heat	Constant Profiles Fig 2.5				Altered (flex.) Profiles Fig 2.6			
		Max Load /Kw		Energy /Kwhrs		Max Load /Kw		Energy /Kwhrs	
		Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g
11-15 Dec	All	20.6	0	565.0	0	25.3	0	724	0.0
19-23 June	All	4.4	-7.7	16.2	-190	7.0	-8.0	40	-205.0
9-13 Oct	All	6.0	-2.98	65.3	-17	8.3	-3.7	115	-22.0





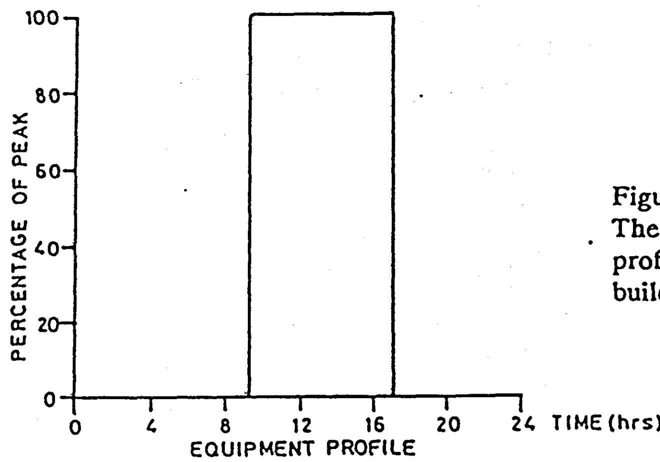
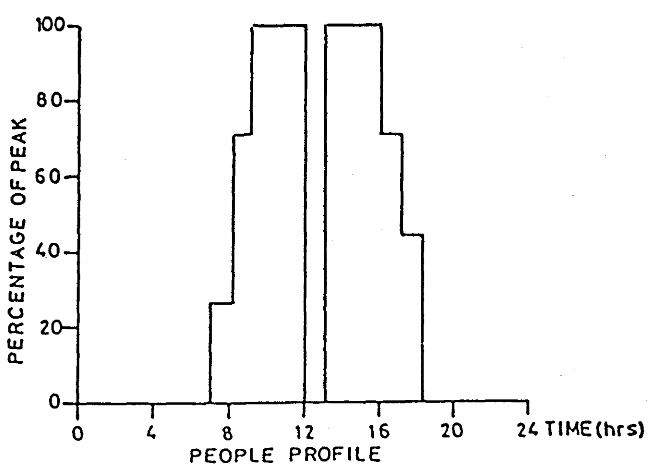
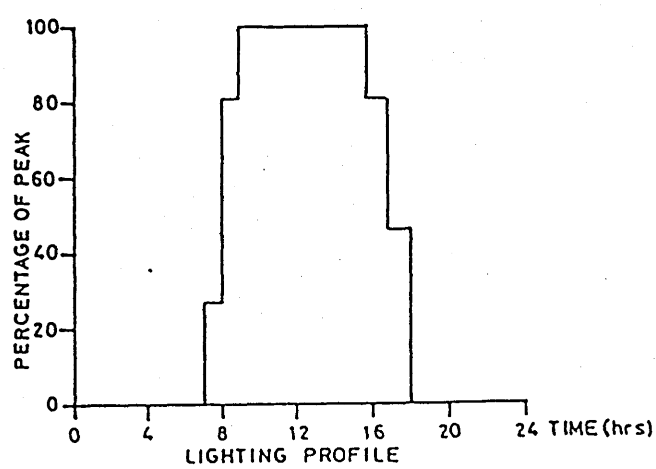


Figure 2.5
The constant internal heat gain profiles of the small office building (9−17) hours





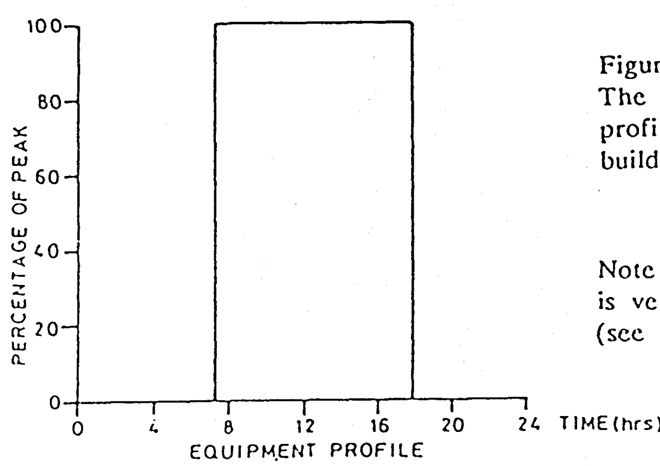


Figure 2.6
The altered internal heat gain profiles of the small office building (7−18) hours

Note: Since equipment heat emissior is very small we kept it constant (see Table 2.2)

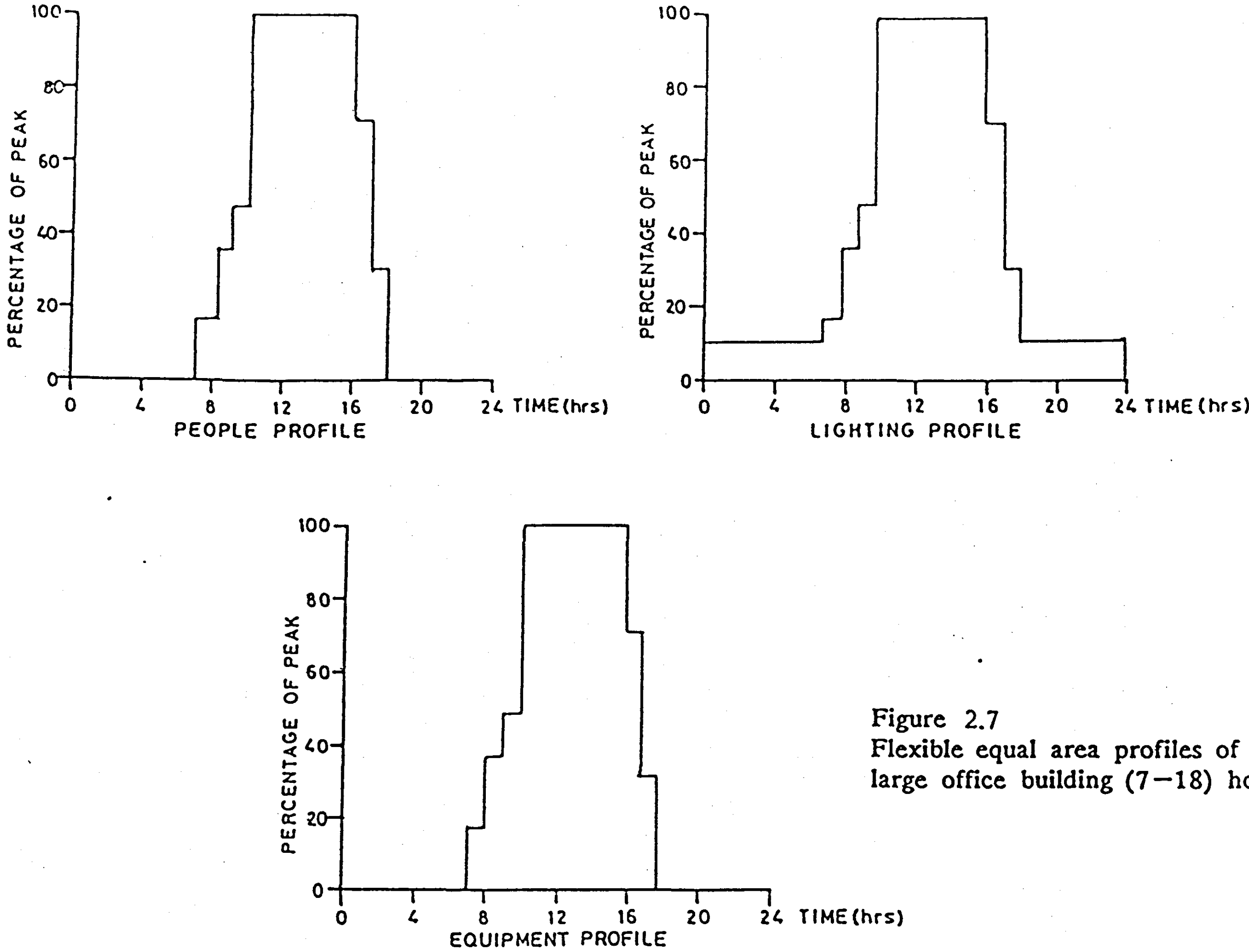


Figure 2.7
Flexible equal area profiles of the large office building (7−18) hours

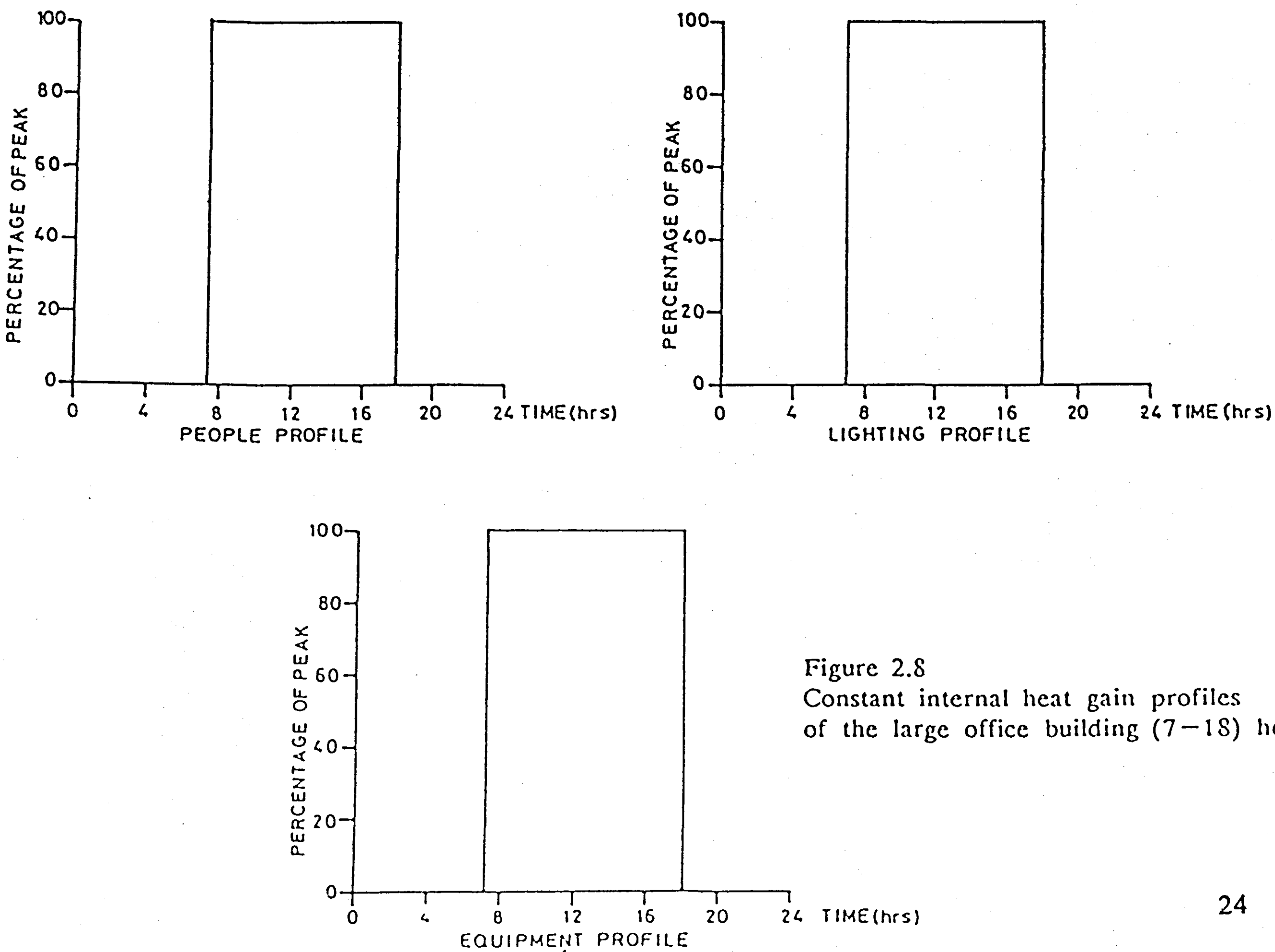


Figure 2.8
Constant internal heat gain profiles of the large office building (7−18) hours

TABLE 2.5

Loads and Energy Requirements of the Large Office Building When the Area (the total amount of heat gain from each component) of the Constant and Flexible Profiles Were Equal. See Figures (2.3) and (2.7).

Simulation Period	Sources of Heat	Constant Profiles Fig 2.3				Altered (flex.) Profiles Fig 2.7			
		Max Load /Kw		Energy /Kwhrs		Max Load /Kw		Energy /Kwhrs	
		Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g
11-15 Dec	All	329.9	-101.0	2926.0	-1429	364.6	-119.9	5327.7	-1544.7
19-23 June	All	41.3	-351.4	88.8	-10782	87.5	-350.0	500.1	-10772
9-13 Oct	All	114.5	-225.0	703.5	-6676	126.0	-234.6	1330.5	-6126.1

TABLE 2.6

Loads and Energy Requirements of the Large Office Building When the Building Occupation Period and the Control Strategy Were Exactly the Same in Both Profiles. See Figures (2.8) and (2.4).

Simulation Period	Sources of Heat	Constant Profiles Fig 2.8				Altered (flex.) Profiles Fig 2.4			
		Max Load /Kw		Energy /Kwhrs		Max Load /Kw		Energy /Kwhrs	
		Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g
11-15 Dec	All	327.7	-135.0	2684.6	-3060	355.6	-127.0	3981.6	-2006.2
19-23 June	All	87.0	-369.4	340.1	-15030	87.0	-354.6	450.5	-12615.2
9-13 Oct	All	117.0	-259.3	663.4	-9638	117.0	-247.2	1045.9	-7640.0

the building control strategy are exactly the same in both profiles (i.e. constant and flexible). The altered (flexible) profiles are the same as shown in Figure 2.4 while the constant profiles are shown in Figure 2.8. Results of building energy requirements of both profiles are listed in Table 2.6. For the small office building, the constant profiles shown in Figure 2.9 and the flexible profile shown in Figure 2.6 were used respectively. The results of the building energy requirements are listed in Table 2.7.

TABLE 2.7

Loads and Energy Requirements of the Small Office Building When the Building Occupation Period and the Control Strategy Were Exactly the Same in Both Profiles. See Figures 2.9 and 2.6.

Simulation Period	Sources of Heat	Constant Profiles Fig 2.9				Altered (flex.) Profiles Fig 2.6			
		Max Load /Kw		Energy /Kwhrs		Max Load /Kw		Energy /Kwhrs	
		Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g	Heat'g	Cool'g
11-15 Dec	All	21.8	0	653.0	0	25.3	0	724	0
19-23 June	All	5.0	-8.2	22.4	-253	7.0	-8.0	40	-205
9-13 Oct	All	6.3	-4.1	59.0	-28	8.3	-3.7	115	-22

In summary, three cases were covered in this study. The first case was when the occupation period and the energy from the internal heat gains were different in both constant and flexible profiles; the second case was when the energy from the internal heat gains was equal in both profiles but occupation periods were still different, and the third case when the occupation periods started and ended at the same time but the energy from the internal heat gains

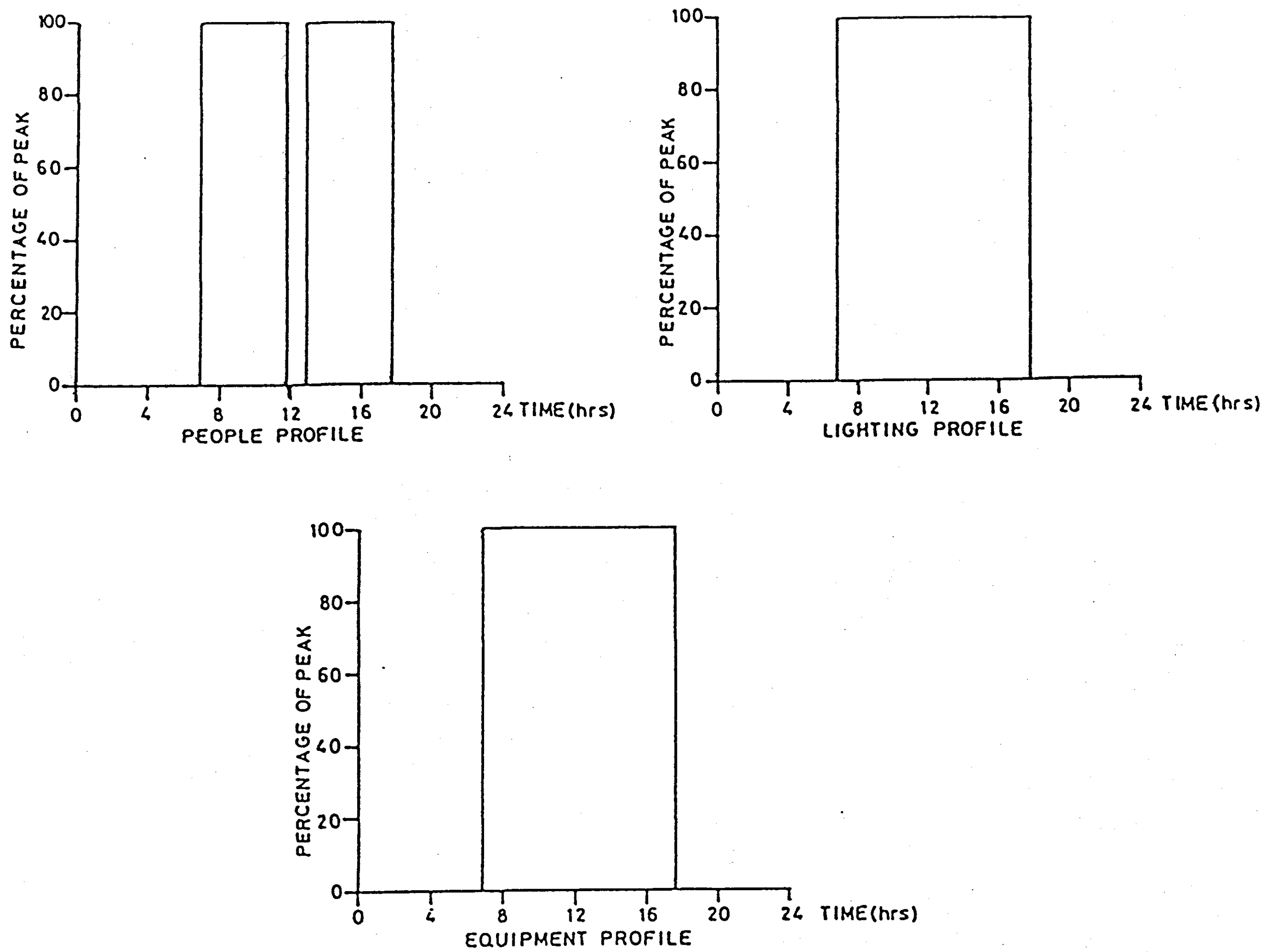


Figure 2.9
The constant profiles of the small office building (7−18) hours

was different.

Figure 2.10 summarizes the three cases considered in this analysis.

2.3 RESULTS ANALYSIS

Before analysing the cases and results described in the previous section, it is important to indicate that ESP performs an energy balance for each zone of the building at each time-step [1.1.2.]. Since all energy predictions were based on hourly time-steps, the energy balance for each zone therefore was performed simultaineously and repeatedly at each hour of the day. The compared cases of both buildings are summarized in the form of a chart in Figure 2.10. Tables of results show the maximum heating/cooling loads, and the total building energy requirements. Due to the high energy emitted by the internal heat sources, the large office required some cooling periods even in winter, to maintain the building design conditions. See Figure 2.11. The results of the first case are listed in Tables 2.3 and 2.4. These show the comparison of constant and flexible profiles when the occupation periods and the energy from the internal heat gains were different. It can be seen that the flexible profiles caused higher loads and energy requirements. For example from Table 2.3 the building energy requirement for the winter week was 36% higher for heating while for the summer week, the cooling energy requirement was 17% higher. This could be explained in the following way:

(a) Due to the early start of the occupation period (i.e. 2 hours earlier), the maximum heating load was higher. For example, for the large office in the winter week it was higher by 8%. For each week it was calculated at the first hour of preheating (5-6 a.m.) of the first simulation day. Figure 2.11 shows the plant load profile of zone (1) of the large office for the winter week. This profile goes up and down between heating and cooling (according to the external conditions and internal heat gains), to maintain the zone design conditions. (See internal air temperature).

(b) Due to the higher energy emitted by the internal heat sources and longer

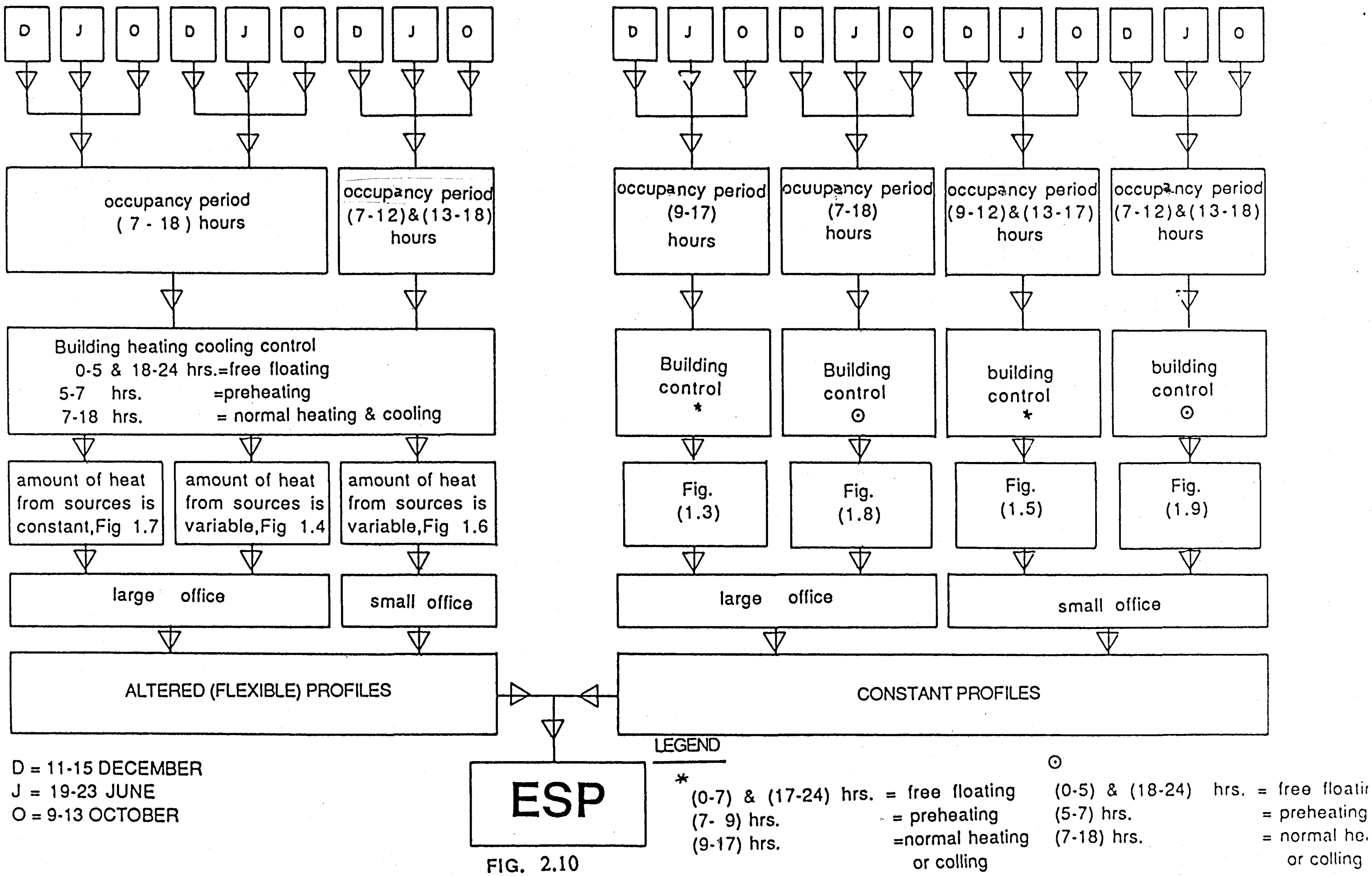


FIG. 2.10

FLOWCHART OF THE COMPARED CASES OF THE CONSTANT & FLEXIBLE PROFILES OF INTERNAL HEAT GAINS

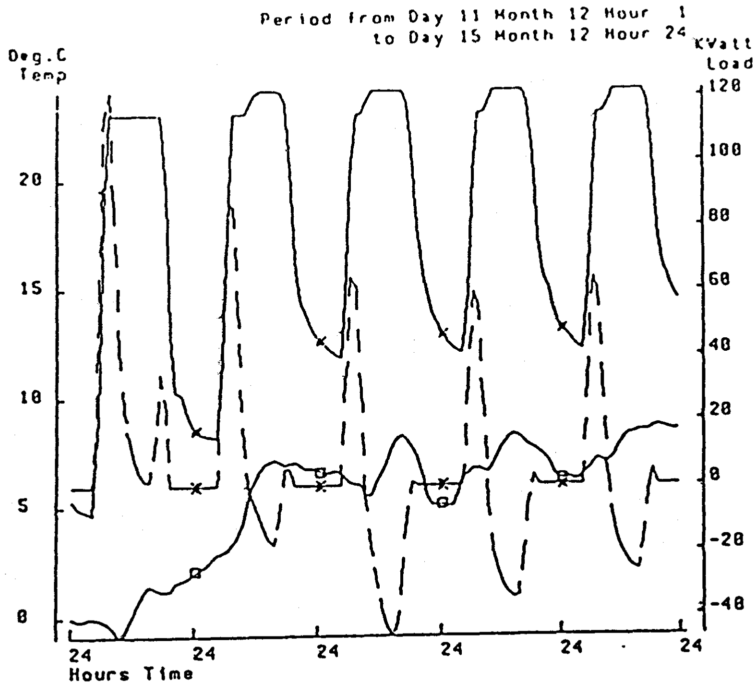


Figure 2.11
Plant load and internal air temperature profiles of Zone 1 of the large office (flexible profiles)

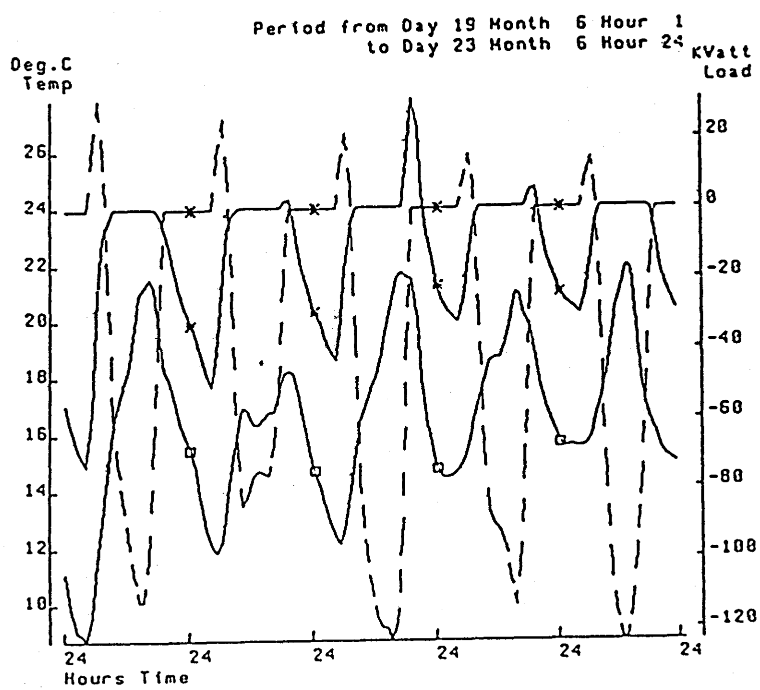


Figure 2.12
Plant load and internal air temperature profiles of Zone 1 of the large office (flexible profiles)

Legend

-----*----- Plant Load Profile
———*——— Internal Air Temperature Profile
———⊟——— External Air Temperature Profile
+ve Heating
−ve Cooling

occupation period, the maximum cooling load was higher. For example, the maximum cooling load of the flexible profile was 25% higher than the constant profile for the winter week of Table 2.3. The time of occurance of the maximum cooling load varies during the day depending on the transient, solar, thermal storage and internal heat gain effects. ESP identifies the maximum cooling load over the whole simulation period as shown in Figure 2.12. Figure 2.12 shows the plant load and internal air temperature profiles for the summer week in relation to the external air temperature.

(c) Due to the longer occupation period (3 hours more per day), the heating and cooling energy requirements were higher. These differences were consistent in both analysed buildings. A larger energy gain from the flexible profile of the staff implies that more man-hours were worked. This is not a valid basis for a comparison. It therefore became important to investigate the case when the area under both profiles was equal (i.e. the energy from the internal heat gains of both profiles were considered to be equal). This case was investigated for the large office building only and the results are listed in Table 2.5. From these results the following points could be drawn:

(a) In all simulated weeks, the flexible profiles caused a higher maximum heating load and heating energy requirements. For example, in the winter week the heating energy requirement was 82% higher. This could be related to the early start of the heating system operation and the longer occupation period respectively. This implies that the longer occupation period has had a significant effect on the building heating energy requirements. The dominating cold and changeable climate of the U.K. had imposed a high requirement for heating, especially in the early morning and evening hours.

(b) The differences in the maximum cooling loads and cooling energy requirements are not as significant as for heating. The cooling energy requirement was 8% higher for the flexible profiles of the winter week while it was 0% approximately for the summer week. These show that the difference in occupation periods made a small difference in the building thermal storage. As mentioned earlier, this was related mainly to the climate of the U.K. If these profiles were investigated in a tropical climate the differences in the cooling energy requirements would probably go up significantly.

The results of the last investiaged case are listed in Tables 2.6 and 2.7 for both buildings. In this case, the occupation period and control strategy were exactly the same in both profiles. From Figure 2.8 and 2.4 it is obvious that the areas (i.e. the energy emitted from each source) of the constant profiles are larger than the areas of the flexible profiles. For that reason the heating energy requirements caused by the flexible profiles were higher (e.g. 48% higher for the winter week of Table 2.6 while the cooling energy requirements were lower (e.g. 19% lower for the summer week).

The results of both buildings show that the difference in the total amount of internal heat emission caused significant differences in the total heating and cooling energy requirements of the simulated periods. Due to the high heat emission suggested by the constant profiles, the heating energy requirement was lower, while the cooling energy requirement was higher. Generally speaking, due to the use of the U.K. climatic data, the differences of the heating energy requirements were significantly higher than the differences of the cooling energy requirements.

2.4 CONCLUSION

The following three cases were tested in this analysis in order to investigate the effect of considering the variability of internal heat emission with time. This variation was tested mainly for the morning arrival and afternoon departure periods based on hourly time-steps.

Case One:

The suggested constant and flexible profiles of each source of internal heat was considered to be different in the following:

(a) The total amount of heat emission (the areas of the profiles).

(b) The occupation periods (start and end times).

The results from both buildings indicated that for all simulated weeks there were significant differences in the building heating and cooling energy requirements.

Case Two:

The constant and flexible profiles have had the following condition:

(a) The amount of heat emitted from each source was equal (equal areas of the profiles).

(b) The occupation periods were different.

The results indicated that for all simulated weeks there were significant differences in the heating energy requirements only.

Case Three:

The constant and flexible profiles of each source have had the following condition:

(a) The amount of heat emitted from each source was different (different areas).

(b) The occupation periods started and ended at the same time. The results from both buildings have shown that there were significant differences in building heating and cooling energy requirements.

Generally speaking, from all cases the differences of the heating energy requirements were significantly higher than the differences of the cooling energy requirements.

It could be concluded therefore that the consideration of the variation of the heat emission from the internal heat sources with time is important. An accurate estimation will improve the estimation of the total building energy requirements. Subsequent stages of the project were justified therefore and should include consideration of the following items:

1. Predicting building occupancy patterns as a first stage. It could be established through the collection of real life data concerning movements of people, breaks and absences for different types of buildings which run a flex-time system (office, factory, warehouse). This is not only important for

the purposes of estimating the heat emission from people, but also for other purposes such as building ventilation, air quality, lighting and equipment use.

2. Predicting artificial lighting use in relation to occupancy and daylight level. This will give an accurate estimation of the power supply and the heat emitted from them.

3. Predicting equipment use in relation to occupancy. This would include the definition of their mode (running or stand-by modes) hence estimating the heat emission accordingly.

If the required data and information concerning each item were available, suitable stochastic techniques could be used therefore to establish a model in order to predict the heat emission from each item.

3 *DATA COLLECTION AND PROCESSING*

3.1 PRELIMINARY ANALYSIS ON SAMPLE DATA

As mentioned in Section 1.3, in order to establish an occupancy pattern model with sufficient accuracy, the size and the period of time for the data collection was decided through the following preliminary analysis:

3.1.1 Objectives

The objectives of this analysis are as follows:

(a) To develop suitable approaches for handling and processing the data.

(b) To have an indication of the variation of arrival and departure times of the building staff from one day to another and from one department to another.

(c) To have an indication of the correlations between times of arrival and departure and between times of arrival and durations of stay.

(d) To have an indication of the statistical distribution of the times of arrival/departure and durations of stay.

(e) To decide therefore about the quantity the data required to be collected.

3.1.2 Statistical Analysis of Selected Samples of Data

Four samples of data taken from the first office building (the Scottish Mutual Assurance Society) were examined in the analysis. Each sample contained times of arrival and departure of the staff of particular departments on a particular day. These were selected as follows:

(a) Two samples of department (6) of the building (the largest department, 64 persons). The first sample is for Monday and the second is for Friday.

(b) Same as (a) but for department (1) (58 persons).

On a normal day each individual of the staff has four records of time. The first record represents the time of arrival in the morning, the second is the departure for lunch, the third is the arrival after lunch, and the fourth is the last departure. The flexi-time recording system have records all these times when each individual clocked in and out throughout the day. A sample of these records is presented in Figure 3.1. To show the randomness of staff arrival and departure during the working day, the pattern of each person of department (1) is presented in Figure (3.2). Each continuous line represents the duration of stay inside the building. It can be seen that these durations varied from one person to another. It shows also the overlap that occured at the lunch break period (i.e. the space is not empty during the period of lunch).

To show the sequence of the staff arriving in the morning (from the first arrival to the last one), the arrival times of Figure 3.2 were sorted out and plotted in Figure 3.3. This figure indicates that the statistical distribution of the arrival times of the morning is likely to be normal. It indicates also that an early arrival to the building is not neccesarily followed by an early departure for lunch. The sequence of the staff departing for lunch is presented in Figure 3.4. It shows that lunch duration varies from one person to another. The sequence of arrivals after lunch and the sequence of departures home could be presented in the same way. The profile of the number of people occupying this department is shown in Figure 3.5. These figures present an idea about what the staff arrival and departure sequences look like. Some of the statistical tests implemented in the MINITAB PACKAGE PROGRAM (1985) [3.1.1] have been carried out on these samples of data. These tests are explained below:

1. Test of correlation

The correlation between the arrival and departure times of each period (morning and afternoon) was tested to check if the times of departure

Dep't No.	BRC	ARIVE	DPART	ARIVE	DPART	ARIVE	DPART	Codes of Absences
0006	001	08.28	12.11	13.16	17.04	*****	*****	000
0006	001	*****	*****	*****	*****	*****	*****	000
0006	001	08.36	12.11	13.24	*****	*****	*****	001
0006	001	08.41	12.29	13.48	*****	*****	*****	001
0006	001	09.45	12.05	13.19	16.28	*****	*****	000
0006	001	08.40	12.11	12.50	*****	*****	*****	001
0006	001	09.02	12.38	13.38	15.57	*****	*****	000
0006	001	*****	*****	*****	*****	*****	*****	000
0006	001	09.57	12.11	12.45	16.27	*****	*****	000
0006	001	08.30	12.05	13.11	16.28	*****	*****	000
0006	001	09.06	12.33	13.48	16.44	*****	*****	000
0006	001	08.12	12.01	13.27	16.10	*****	*****	000
0006	001	08.12	12.28	13.11	16.17	*****	*****	000
0006	001	08.21	12.28	13.25	16.16	*****	*****	000
0006	001	08.41	12.29	13.47	17.44	*****	*****	000
0006	001	08.37	12.29	13.48	*****	*****	*****	001
0006	001	08.04	12.28	13.48	*****	*****	*****	001
0006	001	09.06	13.14	13.42	17.59	*****	*****	000
0006	001	09.22	12.29	13.48	17.15	*****	*****	000
0005	001	08.49	12.12	13.24	17.08	*****	*****	000
0006	001	08.40	12.40	13.11	16.24	*****	*****	000
0006	001	*****	*****	*****	*****	*****	*****	008
0006	001	10.08	12.35	14.33	21.33	*****	*****	000
0006	001	09.18	09.35	09.46	12.29	13.48	17.50	000
0006	001	08.21	12.34	13.16	17.11	*****	*****	000
0006	001	09.15	12.06	13.08	17.15	*****	*****	000
0006	001	09.16	14.53	*****	*****	*****	*****	000
0006	001	08.41	13.13	13.42	17.59	*****	*****	000
0006	001	08.48	12.39	13.52	16.45	*****	*****	000
0006	001	08.48	12.20	12.53	*****	*****	*****	001
0006	001	08.16	12.04	13.01	17.07	*****	*****	000
0006	001	08.44	12.05	13.12	17.43	*****	*****	000
0006	001	08.17	12.03	13.16	16.13	*****	*****	000
0006	001	12.39	12.39	13.49	16.08	*****	*****	000
0006	001	*****	*****	*****	*****	*****	*****	000
0006	001	*****	*****	*****	*****	*****	*****	005
0006	001	09.27	12.51	14.00	18.20	*****	*****	000
0006	001	09.06	12.28	13.57	17.00	*****	*****	000
0006	001	08.31	12.10	13.12	15.58	*****	*****	000
0006	001	08.46	12.12	12.57	*****	*****	*****	001
0006	001	08.53	12.24	14.05	*****	*****	*****	001
0006	001	09.24	13.20	13.55	17.01	*****	*****	000
0006	001	09.04	12.36	13.55	17.21	*****	*****	000
0006	001	08.55	13.11	13.58	17.16	*****	*****	000
0006	001	08.43	[illegible]	12.54	17.16	*****	*****	000
0006	001	10.18	12.02	12.28	16.37	*****	*****	000
0006	001	09.41	12.57	13.57	*****	*****	*****	001
0006	001	09.54	12.05	13.34	17.17	*****	*****	000

FIG. 3.1

A Computer Listing Showing Arrival/Departure Times and Codes of Absences

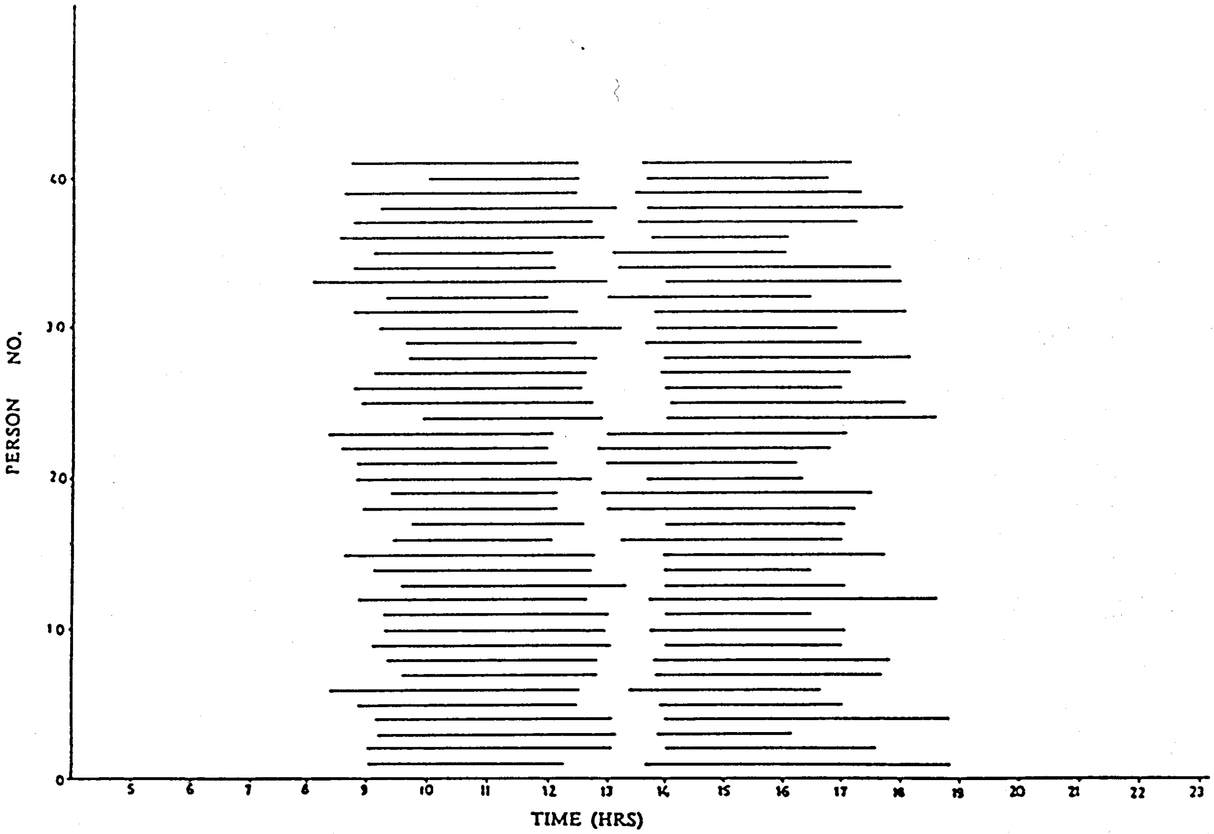


FIG. 3.2

Observed Staff Patterns of Department 1 on Monday 23.2.1987

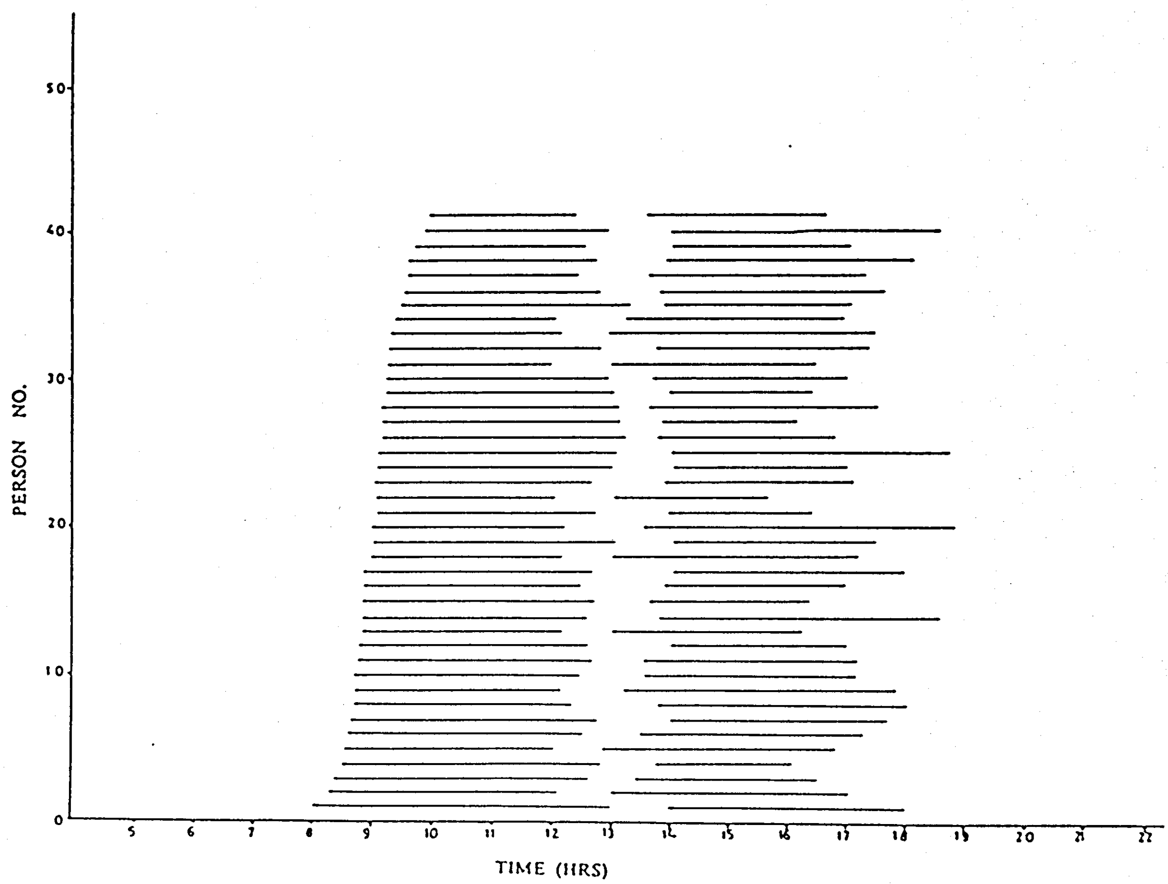


FIG. 3.3

Sequence of Staff Arriving in the Morning

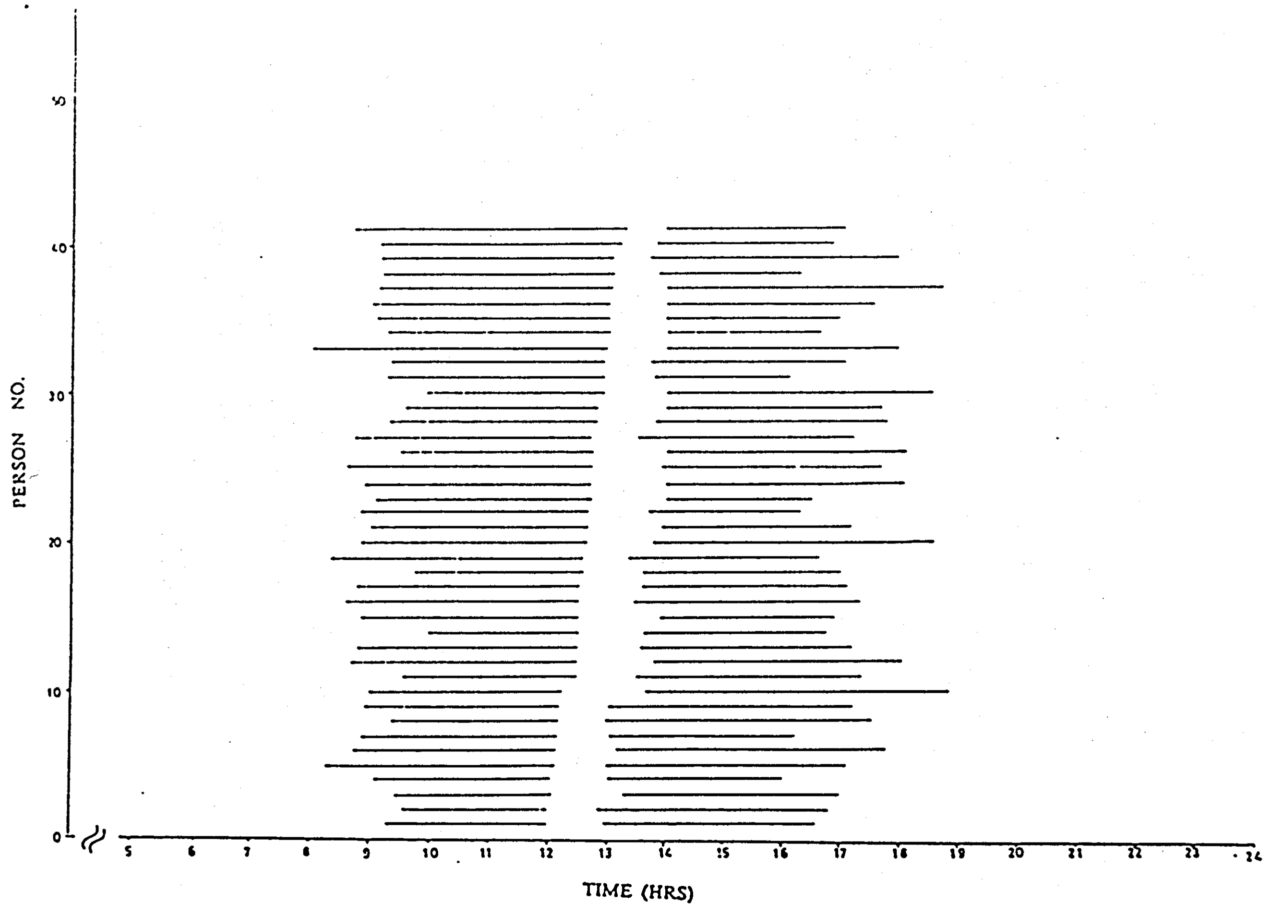


FIG. 3.4

Sequence of Staff Departing for Lunch

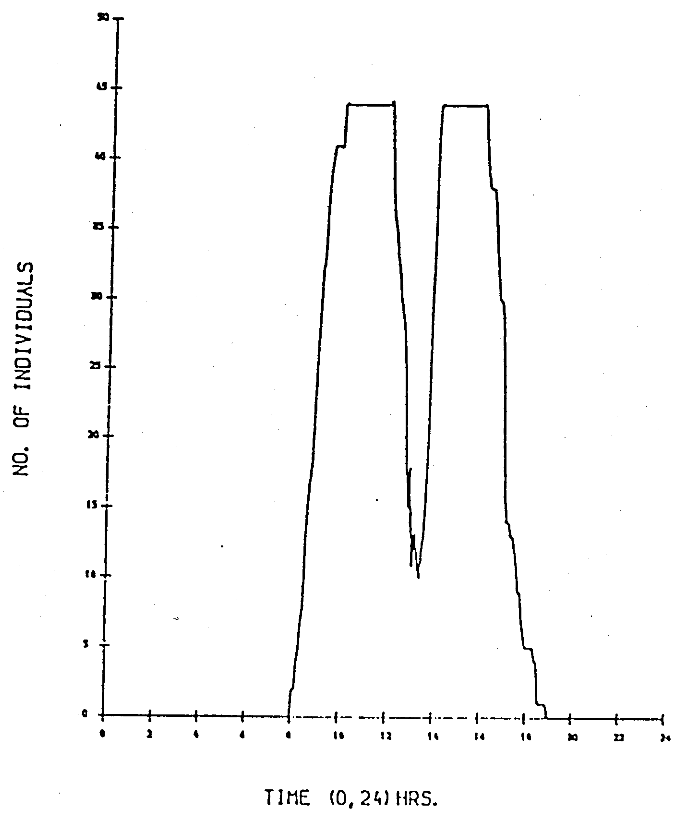


FIG . 3. 5

THE OBSERVED PROFILE OF THE STAFF OF DEPT . 1

depend on the times of arrival. The correlations between time of arrival in the morning and duration of stay in the morning, time of departure for lunch and duration of lunch, and time of arrival after lunch and duration of stay for the afternoon) were checked to find out if they are dependent. Testing results of all samples have indicated the following points:

(a) The time of departure for lunch is independent of the time of arrival in the morning (a very weak correlation). But there was a strong negative correlation between the duration of stay of the morning and the time of arrival.

(b) There was a strong positive correlation between times of departure for lunch and times of arrival after lunch. While the duration of lunch was independent of the time of departure for lunch (a very weak correlation).

(c) The times of last departure were independent of the times of arrival after lunch (a very weak correlation). Similarly, there was a weak correlation between the durations of stay of the afternoon and the times of arrival after lunch.

2. Test of Statistical Distribution

Figures 3.3 and 3.4 have shown that the times of arrival or departure are likely to be normally distributed. Tests of normality (normal probability scores test) have been carried out on the four times of arrival and departure and on the three durations of stay (morning, lunch and afternoon). The results of this test revealed that the arrival and departure times and the durations of stay are all normally distributed.

3. Test of Significance

Since a test of statistical distribution on the samples revealed that all times of arrival, departure and the durations of stay are normally distributed, following tests of significance could therefore be carried out. The F-TEST (difference between two sample variances) and T-TEST (difference between two sample means) have been carried out over the four samples and the following cases investigated.

(a) The variation between the week days (Monday from Friday).

F-test has shown that the variance of the times of arrival for Monday morning is not significantly different the variance of arrival times for Friday morning and similarly for the durations of the morning, the departure times for lunch, the durations of lunch, the arrival times after lunch and the durations of the afternoon. A T-test therefore was carried out. This test has shown the same results.

(b) The variation between the building departments.

The same tests carried out in (a) above were carried out on department (1) against department (6). The results of these tests have shown that there were no significant differences between these departments for arrival and departure times and durations of stay.

3.1.3 Conclusion

The statistical tests carried out on the four samples have shown the following points:

(1) The time of departure of any person for lunch is independent of the time of his arrival in the morning. The duration of lunch is independent of the time of departure for lunch and the duration of stay for the afternoon is independent of the time of arrival after lunch.

(2) Variation of people arrival/departure times between Monday and Friday is not significant, neither is the variation from one department to another. Since these indications have been drawn from very few samples, it was not possible to be considered as a definite conclusion. It was decided therefore to collect more data to cover the daily, seasonal and departmental variations completely and to check that the results of new data should agree with the results of this analysis. Then it would be possible to combine all the

new data in one population to represent accurately the real life situation and from this it would be possible to establish a simulation model of occupancy patterns.

The new data was selected as follows:

From the first office building

(1) Six weeks scattered over a year were selected for department (1) and department (6) of the building. These weeks were 2-6 February, 1987, 9-13 March, 1987, 18-22 August, 1986, 22-26 September, 1986, 20-24 October, 1986 and 17-21 November, 1986. Unfortunately the data for the months of April, May, June and July was not available because the computer of the flexi-time system was installed in July 1986 and the data was collected in February 1987. The tests for seasonal variations were made and showed no significant differences.

(2) Two weeks for all building departments (the summer week of 19-22 August and the winter week of 2-6 February) were selected to allow a double check to be made for consistency.

(3) The manual records of the visitors' data of this building were selected for the same six weeks as for (1).

From the second building (The South of Scotland Electricity Board)

This was a complex of three buildings, the new building (492 persons), the main building (146 persons) and the computer building (82 persons). The available data about all the departments in each building was collected for the following weeks:

1. The winter week (23-27 February)
2. The spring week (6-10 April)
3. The summer week (15-19 June)

This data was collected in steps, because the personnel department of this building throw out the data for each month after payment assessment (that is three months later). Since the data was collected before autumn 1987, the data of this season was not available. The test for seasonal variations revealed that the data of this week was not needed because there were no significant variations.

Data processing and manipulating for both buildings will be explained in detail in the following section.

3.2 THE DATA OF THE FIRST BUILDING (SCOTTISH MUTUAL ASSURANCE SOCIETY)

This section deals with the processing and manipulating of the staff and visitors data separately as explained below.

3.2.1 Staff Data

This building contains 21 departments. The smallest department was occupied by 1 person, while the largest department was occupied by 64 persons. As shown in Figure 3.1, the data of each department was available in a separate form. Therefore it was easy to punch the data of each department in a separate file and save it in the computer. For the total collected period, the number of the files were 250. The file of each department was defined by the department name and the date. A computer program was written to convert the fraction of time in minutes to decimal form (e.g. 8 hours and 45 minutes = 8.75 hours). Before any statistical analysis was carried out, it was necessary to handle the missing records in each file, (see row 3 of Figure 3.1) where the time of the last departure is missing. Also, extra records, i.e. persons with more than four records in a day, were required to be handled. See row 24 of the same figure.

Rather than ignoring the data about a person with a missing record, the mean value was substituted. For example, a missing time of departure home was substituted by the mean value for the last departure time of all department staff.

A survey of the data of all departments showed that the case of a person clocking in or out more than four times was very rare. When it did occur it was because the staff were forced to clock in or out even if they left the building for a few minutes. It was found also that these extra departure/arrival times were for short periods of time. Therefore these short absences were ignored because the loss of heat emission during these absences would only have a minor effect on the building energy requirements.

The daily data for each department was regarded as one statistical sample, except departments with a small number of staff; these could not be assumed to be enough of a sample for the purpose of comparison. Therefore the staff of small departments were added together and assumed to be one sample.

The detailed statistical analysis applied on the data of this building will be discussed here, while the techniques developed from the results of this analysis to simulate building occupancy patterns will be discussed in the next chapter.

The MINITAB package program (1985) was used to carry out the statistical analysis. These tests were carried out to find out if the conclusions drawn from the sample data were valid.

1. <u>Test of correlation</u>:

For each collected week (season) the data of each department (sample) has been tested to check if the times of departure depend on the times of arrival, eg was an early arrival of an individual followed by an early departure? Was an early departure for lunch followed by an early arrival after lunch? The durations of stay were also tested against times of arrival or departure, e.g. does the duration of stay for the morning depend on the time of arrival? Does the duration of lunch depend on the time of departure for lunch? Does the duration of stay for the afternoon depend on the time of arrival after lunch?

The results of this test have agreed with the results of the preliminary analysis test, and showed the following points:

(a) The time of departure for lunch is independent of the time of arrival in the morning (for more than 95% of samples the correlation coefficient [c.c.] is less than 0.23). A strong negative correlation existed between durations of stay in the morning and the time of arrival (minimum c.c. is -0.61). An overlap did not exist between times of arrival in the morning and times of departure for lunch.

(b) There existed a strong positive correlation between times of departure for lunch and times of arrival after lunch (minimum c.c. is 0.55) while the duration of lunch was inependent of the times of departure for lunch (for more than 95% of samples the c.c. is less than 0.31). An overlap between the time of departure for lunch and times of arrival after lunch did exist.

(c) The times of last departure were independent of the times of arrival after lunch (for 95% of samples the c.c. is less than 0.35). The same was the case between the duration of stay for the afternoon and the time of arrival after lunch (for more than 95% of samples the C.C. is less than 0.28). No overlap existed between the times of arrival after lunch and the times of the last departure.

2. Test of Normal Distribution

The test of correlation has indicated that the following times and durations are independent: (a) times of arrival in the morning (b) times of departure for lunch (c) durations of lunch (d) durations of stay for the afternoon period. Therefore each one could be simulated separately to form a random pattern for any individual.

However, it was required to test the statistical distibution of each one for normality (the Normal Probability Score Test) in order to adopt a suitable simulation technique. These times and durations were tested for each week and for each department. The primary test of these samples has shown that some samples were slightly askew from the normal distribution. This skewness was investigated by reviewing the data of these samples. It was discovered that this skewness was caused by a very few odd records of times (ie times of arrival or departure which was more or less than the normal arrival or departure time). An example of these odd values is an arrival time of 6.30 am or 11.00 am where the normal arrival/departure times were between 7.30 am and 10.30 am inclusive. These odd records were also found in the times of departure for lunch, the times of arrival after lunch and the times of the last departure. These records of times were taken out and the sample was tested again for normality. The new test revealed that for a confidence level of 95%, all samples were normally distributed. It was thought that the odd records should not be ignored but should be taken into consideration in the simulation model. However, a separate statistical analysis has shown that the odd records represented a very low percentage of the building staff. (The maximum percentage 1% = 4/400 were out of the normal range of 7.30 to 10.30 hrs of the morning arrival time, and 0.5% = 2/400 were out of the normal range of 11.45 to 13.30 hrs of departure time for lunch; 1.25% = 5/400 were out of the normal range of 5 minutes to 2.05 hrs of duration of lunch, and 1% = 4/400 were out of the normal range of 1.35 to 6.00 hrs of duration of the afternoon. Since these records represented a very low percentage of the building staff, and have an unimportant effect on the actual building occupancy patterns, they were ignored.

Figure 3.6 shows the histograms (frequency distribution) of the arrival times of the morning, the departure times for lunch, the duration of lunch, and the durations of afternoon for a random sample of department (1). Though normally distributed, the frequency distribution of each one appeared with a slight random fluctuation from one day to another.

3. Test of Significance. (F-Test and T-Test)

The F-Test and the T-Test were carried at 95% confidence level. One of the main advantages of these tests is that any number of compared samples could be added together to form one population when there is no

```
Midpoint   Count
     7.8       1  *
     8.0       2  **
     8.2       3  ***
     8.4       7  *******
     8.6       4  ****
     8.8       6  ******
     9.0      13  *************
     9.2       6  ******
     9.4       1  *
     9.6       3  ***
     9.8       1  *
    10.0       1  *
```

A -

```
Midpoint   Count
    12.0      11  ***********
    12.2       4  ****
    12.4       6  ******
    12.6       8  ********
    12.8       7  *******
    13.0       8  ********
    13.2       1  *
    13.4       2  **
```

B -

```
Midpoint   Count
     0.4       1  *
     0.6       5  *****
     0.8       5  *****
     1.0      18  ******************
     1.2       7  *******
     1.4       5  *****
     1.6       3  ***
     1.8       1  *
```

C -

```
Midpoint   Count
     2.0       2  **
     2.4       2  **
     2.8       5  *****
     3.2      17  *****************
     3.6      10  **********
     4.0       7  *******
     4.4       1  *
     4.8       2  **
```

D -

FIG. 3.6

Histogram for a Sample of the Staff Data

A - Times of Arrival in the Morning.
B - Times of Departure for Lunch.
C - Durations of Lunch.
D - Durations of Stay in the Afternoon.

significant difference between their variances and means at a certain confidence level. Hence a better estimate of the overall mean and standard deviation could be obtained [3.2.1].

The F-Test and the T-Test were carried out to investigate the following cases:

(a) Testing the variation of arrival/departure times between the week days of the same season. Each day of the week was compared against other days of the same week (e.g. Monday against each of Tuesday, Wednesday, Thursday and Friday and so on). This test was carried out for department (1) and department (6) for each of the six weeks. At a 95% confidence level, the tests have shown that for all compared days of the week, there were no significant differences between the variances and the means of the following times and durations: (1) arrival in the morning, (2) departure for lunch, (3) duration of lunch, (4) duration of afternoon. Therefore for each season, the daily data for each department could be combined together to give better estimates of the mean and standard deviation.

(b) Testing the variation of arrival/departure times between building departments. In this test, the data of each day of the six weeks was compared for department (1) and for department (6). The results of this test showed that there was no departmental variation between the compared times and the durations (1 through 4 in (a) above). Therefore, for any season, the data of all building departments could be combined together to form one population.

(c) Testing the seasonal variation. Since the data of all season's (six weeks) was available for department (1) and department (6), the data of each department was compared in the different seasons (winter & summer, winter & spring, winter & autumn, spring & summer, spring & autumn, summer & autumn). For a 95% confidence level there was no seasonal variation between the mentioned times and durations

(1 through 4 in (a) above).

Broadly speaking, the data of all seasons could be combined therefore for all building departments (i.e. all collected data) to form one large population and to give a better estimate of the overall mean and standard deviation of this type of office building. The mean and standard deviation values of the independent arrival/departure times and durations of stay which would be used in the simulation model are shown in Table 3.1.

TABLE 3.1

The Mean and Standard Deviation Values of Independent Arrival/Departure times and Duration of Stay for Normal Building Staff Obtained from the combined Data of the First Building.

Time/duration	Mean	Standard Deviation
Arrival time for the morning	8.86374	0.51960
Departure time for lunch	12.59636	0.39177
Duration of stay for lunch	0.96696	0.30629
Duration of stay for the afternoon	3.49761	0.69163

3.2.2 Visitors Data

From the arrival and departure times of the visitors the following observations have been drawn:

(a) The visitor's destination (the department to be visited) was not registered. The only available records were the arrival and departure times which were registered at the building reception.

(b) The different maintenance activities in the building were carried out by an external maintenance staff (a contract with external companies) and their arrival/departure times were registered with the visitors records.

(c) The maintenance staff arrival times were often earlier than the arrival times of normal building visitors and the times of departure were often later than the visitors departure times.

(d) Due to the variety of the maintenance activities, the records of arrival and departure times of the maintenance staff were observed throughout the year.

Again the three statistical tests mentioned above were carried out for each of the six weeks and the results of these tests are as follows:

(1) The correlation test has shown that the visitors' times of departure were independent of the time of arrival (i.e. an early arrival of a visitor is not necessarily followed by an early departure and vice versa). For a 99% confidence level the maximum correlation coefficient was 0.29. But a strong negative correlation did exist between the duration of stay inside the building and the time of arrival (the minimum correlation coefficient was -0.54). An overlap was noticed between times of arrival and departure of the visitors.

(2) The test of statistical distribution for the daily data of each of the six weeks indicated that the times of arrival/departure and durations of stay had a discrete distribution. The frequency distribution of each one fluctuated randomly from one day to another. A histogram of

arrival/departure times and durations of stay of the visitors on a particular day are presented in Figure 3.7. It shows that these distributions are far from normal. The peak numbers of arrivals at 8 am and departures at 5 pm were related mainly to the external maintenance staff mentioned earlier. The visitor pattern problem was solved by a different stochastic approach. This will be discussed later.

(3) Tests of significance. The F-Test and the T-Test were performed to explore the following variations:

(a) The variation of arrival/departure times and durations of stay between the week days of the same season. For a 95% confidence level this test indicated that the variation between the days of the week was not significant. Therefore the daily data of the same seasons could be combined together to form one population.

(b) The seasonal variation. The outcome of this test indicated that the variation from one season to another was minor at a 95% confidence level. The visitor data of all seasons could be combined therefore to give the best figure of visitor patterns.

3.3 THE DATA OF THE SECOND BUILDING COMPLEX (SOUTH OF SCOTLAND ELECTRICITY BOARD)

As mentioned in Section 3.1.3, this building was a complex of three offices, the first office "the new building" contained five departments. These were occupied by 33, 35, 104, 147 and 108 individuals respectively. The second office "the main building" contained four departments. These were occupied by 8, 19, 50 and 69 individuals respectively. The third office "the computer building" contained one department occupied by 82 individuals.

A further statistical test was performed for these offices in order to check the variation of arrival/departure times between the three offices. The results of the statistical analysis on these three offices showed an agreement with the results of the previous building except for some samples of the

```
Midpoint    Count
       7        1  *
       8       15  ***************
       9       10  **********
      10        4  ****
      11        9  *********
      12        2  **
      13        1  *
      14        5  *****
      15        3  ***
      16        4  ****
      17        2  **
```

A -

```
Midpoint    Count
      10        3  ***
      11        2  **
      12        6  ******
      13        5  *****
      14        3  ***
      15        2  **
      16       12  ************
      17       22  **********************
      18        1  *
```

B -

```
Midpoint    Count
       0       10  **********
       1       14  **************
       2        3  ***
       3        4  ****
       4        1  *
       5        0
       6        0
       7        0
       8       12  ************
       9       12  ************
```

C -

FIG. 3.7

Histogram for a Sample of the Visitors' Data

A - Times of Arrival.
B - Times of Departure.
C - Durations of Stay.

computer office. these samples have indicated some departure from the results of other offices in the following cases:

(a) A negative correlation between the durations of stay in the afternoon and the times of arrival after lunch (maximum c.c. was -0.81).

(b) Durations of lunch showed some skewness from the normal distribution.

(c) At a 95% confidence level, the times of departure for lunch and the duration of lunch were significantly different between this office and the other two offices.

The reason behind the disagreement of these few samples has been investigated and it was found that it was due to the lack of an appreciable number of records concerning the times of departure/arrival for the lunch period. These records were missed because most of the office staff did not clock out/in when they left the building for lunch. In fact, it was realized that each individual should have a compulsory lunch break of 30 minutes at least. Therefore, if these records had been available this sample would not be significantly different from the samples of the other offices.

Since the results of the tests of significance have shown no daily, seasonal, departmental and building variations, it became possible to combine all the collected data in one population in order to give a better estimation of the overall means and standard deviations. The mean and standard deviation values of the independent times of arrival/departure and durations of stay are listed in Table 3.2.

Generally speaking, it is worth mentioning that the office buildings analyzed are situated in two different locations. The first building was located in the city centre and was near all routes of transportation while the other office only had access to a few transportation routes. However, the summarized statistical results of both buildings implied that this factor had little effect on the building occupancy pattern. Tables 3.1 and 3.2 show that one of the main reasons for the small differences between the mean values and the standard deviations of both buildings is related to their location. For accuracy, these values will be used in the simulation model according to the building location.

TABLE 3.2

The Mean and Standard Deviation Values of Independent Arrival/Departure Times and Duration of Stay for Normal Building Staff Obtained from the Combined Data of the Second Building.

Time/duration	Mean	Standard Deviation
Arrival time for the morning	8.54580	0.46590
Departure time for lunch	12.51900	0.41100
Duration of stay for lunch	0.70403	0.32400
Duration of stay for the afternoon	3.59460	0.65830

REFERENCES

[3.1.1] B F Ryan, B L Joiner and T A Ryan, MINITAB Handbook, Second Edition, 1985.

[3.2.1] J D Thompson, Basic Statistical Techniques for the Course on Engineering of Building Services, December, 1986.

4 *STOCHASTIC SIMULATION OF BUILDING OCCUPANCY PATTERNS AND THE RESULTANT HEAT EMISSION*

4.1 INTRODUCTION

In the previous chapter, the different statistical analysis of the data of both office buildings was discussed. In this chapter, the model developed from the results of this analysis will be discussed in detail. Basically, occupancy pattern simulations are based on the random variation of the occupants arrival/departure times from one day to another. For each individual, the model predicts an arrival/departure time or duration of stay.

For each simulated day and for any zone of the building, the logic of the occupancy model was constructed as follows:

1. Predicting the number of absences.

This problem was approached in two ways. The first way was based on the data of the first office building. The random number of absences due to holidays or sickness were simulated separately, and the total number of absences then calculated by adding them together. The second way was based on the data of the second building. A random total number of absences was simulated directly irrespective of the reasons for absence. For both ways the number of the staff arriving on a particular day was calculated by subtracting the predicted number of absences from the total number of the staff occupying the zone.

2. Simulating a random pattern of each member of staff by predicting an arrival time in the morning, departure for lunch, an arrival time after lunch, and finally the time of the last departure. Two subroutines were introduced based on the same method, while the values of mean and standard deviations were based on the building location. The number of the staff occupying the zone at each time step was indentified by

classifying the arrival/departure times to suitable intervals depending on the selected time steps.

3. If there were any visitors, their patterns were simulated randomly by adopting another technique. The time of arrival and duration of stay of each visitor was simulated and the time of departure was calculated. The number of visitors existing in the zone was calculated in each time step in the same way as that used for the staff.

4. At each time step, the number of the people occupying the zone was calculated by adding the number of the visitors to the number of staff. The heat emission from their bodies was calculated accordingly. The values of the sensible/latent heat emission per person and the convective/radiative splits of the sensible heat were dependent on the rate of activity and were to be defined by the user of the model. The techniques used to simulate the zone absences, staff and visitors' patterns are explained below in turn and introduced in the form of flowcharts of a computer program written in Fortran 77.

4.2 PREDICTING THE NUMBER OF ABSENCES

The prediction of the absense number was introduced in two ways according to the availability of the data. These were as follows:

4.2.1 The Method Developed from the Data of the First Building

The number of absences was simulated for a particular reason (holiday or sicknesss). These were recognized from the people who did not clock in or out throughout the day while the reason for absence was identified by a code. See Figure 3.1. An absence due to holiday was coded by number 5 and an absence due to sickness was coded by number 8. It was observed that some absences were due to unknown reasons and coded by number 0. The unexplained absences were added to the sickness because both were an unprepared event and happened randomly. As the data for all seasons was available for department (1) and department (6), an F-Test between the proportions of the number of absences due to holidays or sickness (proportion is equal to the number of absences due to holidays or sickness divided by the total number of the staff) of both departments was performed for each season. This test indicated that at a 95% confidence level, there were no significant differences between the values of standard deviation. Therefore the numbers of absences due to holidays or sickness of both departments were added together for each day of the collected weeks. Table 4.1 shows these numbers.

The T-Test was not perfomed because the average (mean) number of absences depended on the size of the department so that it was not valid to compare them in departments of different occupancy number. This fact is worth recognizing because the model deals with zones of different occupancy numbers depending on their sizes. Hence it was assumed that the user of the model would have an idea about the average value. Since the number of sickness absences was governed by chance and the type or location of the building had no effect on its occurrance, it became valid to provide an optional default average value for the user. This value was estimated from the available data as a percentage of the total. For holidays, no default average value was offered because the rules of holidays varied from one office to another and from one location to another. For example, Scottish holidays are different from English holidays so that the user of the program needed to input a suitable value. The random swing from this average value from one day to another was considered by the model, and the technique adopted to simulate a random number of absences due to holidays or sicknes is summarized in the following points:

(1) Table 4.1 shows that the actual daily number of absences due to holidays or sickness varies from one season to another. Table 4.2 shows that the variation between the relative proportions of these numbers are not as significant as the pure numbers (test of significance will be explained).

TABLE 4.1

The Number of Absences Due to Holidays or Sickness Combined for Department (1) and (6)

Day	Feb. Week		Mar. Week		Aug. Week		Sept Week		Oct. Week		Nov. Week	
No.	H	S	H	S	H	S	H	S	H	S	H	S
1	3	10	6	4	23	6	13	11	13	4	11	8
2	3	9	8	9	21	6	11	13	9	7	8	7
3	4	6	5	8	24	4	12	11	10	6	8	7
4	6	9	6	7	23	4	13	13	11	4	7	7
5	6	8	6	9	21	7	20	17	10	8	6	5
TOTAL	22	42	31	37	112	27	69	65	53	29	40	34
DAILY AV'GE	4.4	8.4	6.2	7.4	22.4	5.4	13.8	13	10.6	5.8	8	6.8

TABLE 4.2

Relative Proportions of the Number of Absences Due to Holidays or Sickness

Day	Feb. Week		Mar. Week		Aug. Week		Sept Week		Oct. Week		Nov. Week	
No.	H	S	H	S	H	S	H	S	H	S	H	S
1	0.68	1.19	0.97	0.54	1.03	1.11	0.94	0.85	1.23	0.65	1.38	1.18
2	0.68	1.07	1.29	1.22	0.94	1.11	0.80	1.0	0.85	1.21	1.0	1.03
3	0.91	0.71	0.81	1.08	1.07	0.74	0.87	0.85	0.94	1.03	1.0	1.03
4	1.36	1.07	0.97	0.95	1.03	0.74	0.94	1.0	1.04	0.69	0.88	1.03
5	1.36	0.95	0.97	1.22	0.94	1.3	1.45	1.31	0.94	1.38	0.75	0.74

Code:

H = Holiday (computer code 5)
S = Sickness (computer code 8)

The relative proportions were calculated as follows:

(a) For each week the total number of holidays or sickness was calculated (e.g. for the February week the total numbers are 22 and 42 respectively).

(b) The average daily number was calculated by dividing the total number by the number of days (e.g. 22/5 = 4.2 and 42/5 = 8.4). To be accurate, these averages were not approximated to the nearest integer at this stage because they were required for the calculation of relative proportions.

(c) The relative proportion of the daily number of absences due to holidays or sickness is equal to the actual daily number divided by the average number (e.g. the 2nd of February = 3/4.2 = 0.68 and 10/8.4 = 1.19). In this way Table 4.2 has been completed. The mean value of these relative proportions for any season is equal to 1. That is due to the nature of the process by which they have been calculated.

(2) Seasonal variations between the standard deviation of the relative proportions have been carried out (F-Test) and it was found that at a 95% confidence level, there were no significant differences. For that reason the relative proportions of all seasons were assummed to be one population to give a better estimate of the overall standard deviation. For consistency a further F-Test was performed to check if the standard deviation of the relative proportions of each week was significantly different from the overall population standard deviation. This test showed that no significant differences existed. The overall standard deviation of the population could be used therefore in the simulation of these proportions.

(3) A test for the frequency distribution (normal probability score test) on these relative proportions has revealed that they were normally distributed.

(4) As a consequence of (2) and (3) above, the technique to simulate a

random number of holidays was applied on the normal distribution of the relative proportions. A normal variable is said to have a normal distribution if it takes values in the range $(-\infty, \infty)$ and the probability density function (p.d.f.) is Equation (1) [4.2.1].

$$\text{p.d.f} = \frac{1}{\sigma\sqrt{(2\pi)}} \exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\} \qquad \ldots\ldots\ (1)$$

where x is a random variable, μ is the mean and σ is the standard deviation. The normal p.d.f. (Equation 1) is a bell-shaped curve which is symmetrical about a mode at the value $x = \mu$. The parameter σ is a scale parameter. A plot of the normal p.d.f. is shown in Figure 4.1. When the variable x is expressed in standard units, $z = \frac{x-\mu}{\sigma}$, the equation of the normal curve in its standard form becomes

$$\text{p.d.f} = \frac{1}{\sqrt{(2\pi)}} (e)^{-\frac{1}{2}z^2} \qquad \ldots\ldots\ldots\ldots\ (2)$$

This is a normally distributed curve with mean $\mu = 0$ and standard deviation $\sigma = 1$ and usually denoted $N(\mu.\sigma^2)$
The cumulative density function (c.d.f.) at the standard normal distribution is written

$$Y = \int_{-\infty}^{X} \frac{1}{\sqrt{(2\pi)}} \exp\left(-\frac{Z^2}{2}\right) dZ \qquad -\infty < X < \infty \qquad \ldots\ldots\ldots\ldots\ (3)$$

The c.d.f. has a shape shown in Figure 4.2.
If z is $N(\mu, \sigma)$, the following transformation is often used:

$$x = Z\sigma + \mu \qquad \ldots\ldots\ldots\ldots\ (4)$$

For standard normal distribution the value of Y is between 0 and 1 inclusive, because it is an integration of the p.d.f.

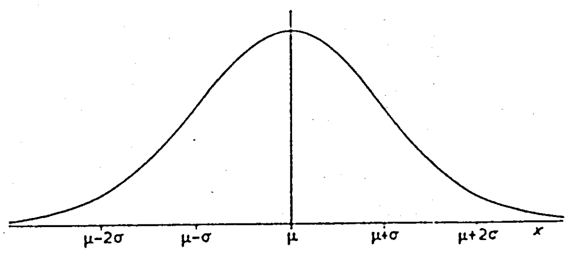


FIG 4.1

The p.d.f. of the normal distribution

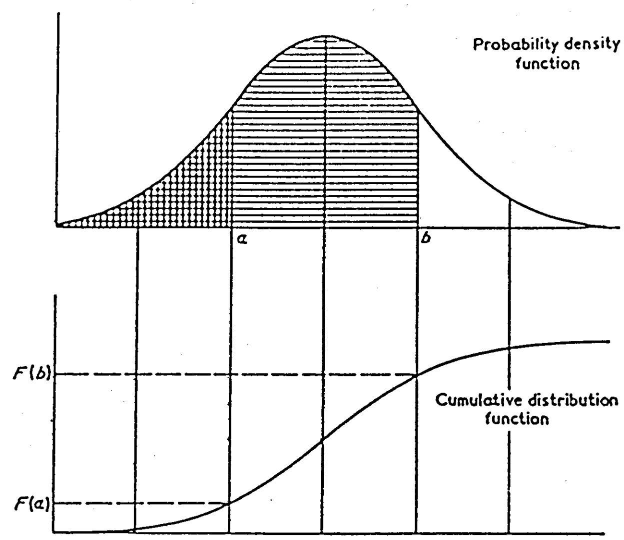


FIG 4.2

The cumulative distribution function

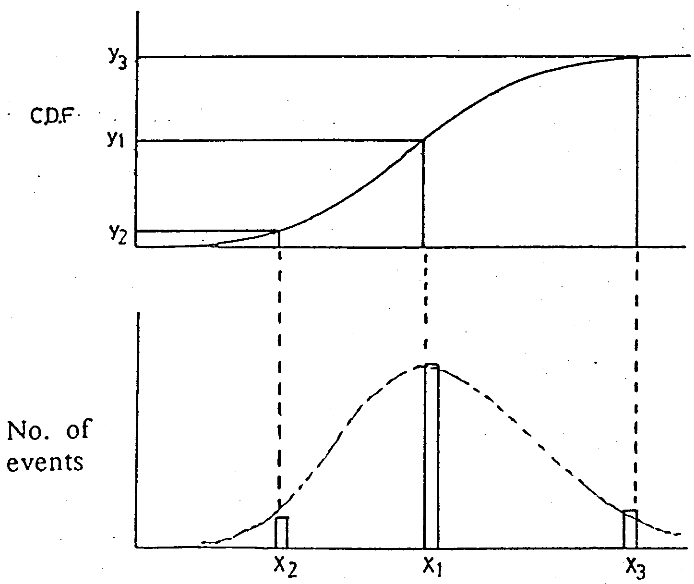


FIG 4.2a

Graphical presentation of the method of predicting an event.

To simulate an event (x) from the frequency of normal distribution, the method is shown graphically in fig. 4.2a.

To simulate a random relative proportion of the number of holidays or sickness, its value was regarded as an equivalent to the variable (x) in Equation (4). The value of Y is generated randomly.

The value of z was obtained from Equation (3) above. From Equation (4), x value (the relative proportion) was calculated, since the mean $\mu = 1$ (mean value of the relative proportions), and σ is the overall standard deviation obtained from the data

for holidays $\sigma = 0.1984$

for sickness $\sigma = 0.21010$

The actual number of absences due to holiday or sickness was calculated by multiplying the simulated relative proportion (x) by the average number ($\bar{\mu}$) which is defined by the user

$$N = x * \bar{\mu}$$

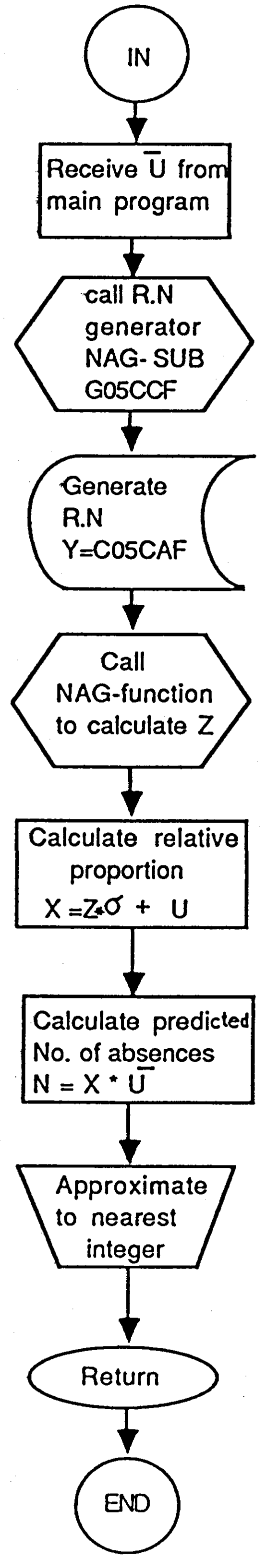
N value was approximated to the nearest integer.

The flowchart of the subroutine used to simulate the number of absences due to holidays or sickness is introduced by Flowchart 4.1.

4.2.2 The Method Developed from the Data of the Second Building

As mentioned earlier, the reason for a person's absence was not given. This is not vital in this analysis, in view of the fact that the interest is ultimately in the total number. The subdivision as for the first building may be easier for the user of the program to input. The total number of absences per day for each department of the three offices is shown in Table 4.3. The proportions of these numbers (proportion = the daily number of absences ÷ the total number of staff) are introduced in Table 4.4. For each week (season), the F-Test results have shown that the variation of the standard deviation of these proportions from one department to another for the same office was not significant. The same was true between departments in all three buildings.

$\bar{U}$ =Average No. of either total absences, absences due holidays or absences due to sickness(input by user)
R.N = random number
Y = random value between 0,1 regard to be equal to c.d.f of normal distribution
Z = obtained from the reverse of c.d.f of normal distribution by using the NAG- function G01CEF
σ = standard deviation
U = mean value of relative propotion =1



Flowchart 4.1
SUBROUTINE 'HOLYDY','SICK','ABSENT'
(simulation of the no. of holidays,sickness, or the total no. of absences)

Table 4.3

The Daily Total Number of Absences in Each Department of the Three Offices

Building department	Total Number of Staff	DAILY TOTAL NUMBER OF ABSENCES														
		February					April					June				
		23	24	*	26	27	6	7	8	9	10	15	16	17	18	19
N1	33	8	6	NO DATA AVAILABLE	8	11	6	5	3	5	4	9	8	8	9	8
N2	104	24	19		26	32	20	21	20	25	20	22	16	21	20	26
N3	208	43	42		44	55	43	43	34	37	43	51	60	57	46	65
N4	147	17	19		20	22	10	17	23	17	27	20	18	20	18	27
NG	35	8	10		11	14	7	4	7	7	6	11	8	8	7	10
M1	69	11	9		19	18	15	8	8	12	10	17	12	16	13	21
M2	8	2	2		2	3	1	0	2	0	0	3	3	2	2	2
M3	50	4	6		7	10	5	8	7	8	9	9	9	7	5	9
MG	19	3	4		3	5	3	1	2	3	5	8	8	7	5	6
C1	82	15	15		15	23	18	14	14	15	19	17	15	17	17	25

Table 4.4

Proportions of Total Number of Absences Drawn from Table 4.3

Building	DAILY PROPORTION OF ABSENCES														
	February					April					June				
department	23	24	*	26	27	6	7	8	9	10	15	16	17	18	19
N1	0.242	0.181	NO DATA	0.242	0.333	0.181	0.151	0.09	0.151	0.121	0.272	0.242	0.242	0.272	0.242
N2	0.23	0.182		0.25	0.30	0.192	0.201	0.192	0.24	0.192	0.211	0.153	0.201	0.192	0.25
N3	0.206	0.201		0.211	0.264	0.206	0.206	0.163	0.177	0.206	0.245	0.288	0.274	0.221	0.312
N4	0.115	0.129		0.131	0.149	0.068	0.115	0.156	0.115	0.183	0.136	0.122	0.136	0.122	0.183
NG	0.228	0.285		0.314	0.4	0.20	0.114	0.2	0.2	0.171	0.31	0.228	0.228	0.2	0.285
M1	0.159	0.130		0.275	0.260	0.217	0.185	0.159	0.173	0.144	0.246	0.173	0.231	0.188	0.304
M2	0.250	0.250		0.25	0.375	0.125	0	0.25	0	0	0.375	0.375	0.25	0.25	0.25
M3	0.08	0.120		0.14	0.20	0.1	0.16	0.14	0.16	0.18	0.18	0.18	0.14	0.1	0.18
MG	0.157	0.210		0.157	0.265	0.157	0.052	0.105	0.157	0.263	0.42	0.42	0.368	0.263	0.315
C1	0.18	0.18		0.18	0.28	0.219	0.170	0.170	0.18	0.23	0.2	0.18	0.20	0.20	0.30

* missing data

Consequently the data of all departments of the three offices was combined for each collected week. See Table 4.5. The relative proportions were calculated and introduced in Table 4.6 These relative proportions were combined in one sample because there was no seasonal variation. The simulation technique used was the same technique introduced for the last building and Flowchart (4.1) explains the process. The program user needs to define an average value for the total number of absences for all reasons, while the random daily swing from this value is contained in the model.

4.3. PREDICTION OF STAFF PATTERNS

From the results of the statistical analysis, it could be concluded that the model of the building staff could have the following characteristics:

(a) The model could be used generally for any department of the building since there was no departmental variation.

(b) The model could be used generally at any day of the year since there were no daily and seasonal variations.

These inferences have reduced the complexity of the model and kept it general rather than specific. It is suggested that the mean and standard deviation values listed in Table 3.1 and 3.2 do not vary significantly from one location to another within the city. However, to achieve high accuracy, these values were used according to location.

The prediction of staff patterns was conceptualy based on the same technique introduced for the simulation of building absences. The number of staff arriving on a particular day was calculated after subtracting the predicted absences from the total actual number of staff. To build a random pattern for each individual, the following parameters were chosen to be predicted:

(a) The arrival time in the morning.

(b) The departure time for lunch.

(c) The duration of stay for lunch.

Table 4.5

The Total Number of Daily Absences for all Building Departments Combined Together

	February		April		June	
	Date	Total Absence	Date	Total Absence	Date	Total Absence
	23	135	6	128	15	167
	24	135	7	121	16	157
	*	153	8	120	17	163
	26	155	9	129	18	142
	27	193	10	143	19	199
	Total	768	Total	641	Total	828
Daily Average	$\frac{768}{5} = 153.6$		$\frac{641}{5} = 128.2$		$\frac{828}{5} = 165.6$	

* missing data substituted by mean value

Table 4.6

Relative Proportions of the Number of Absences

February		April		June	
23	0.8789	6	0.99844	15	1.00845
24	0.85937	7	0.94384	16	0.94807
*	0.99609	8	0.93604	17	0.98430
26	1.00911	9	1.00624	18	0.85749
27	1.25651	10	1.11544	19	1.20169

* missing data

(d) The duration of stay in the afternoon.

The time of arrival after lunch was calculated by adding the time of departure for lunch to the duration of lunch. Similarly the time of departure home was calulated by adding the time of arrival after lunch to the duration of the afternoon. The parameters (a) through (d) were chosen because each one is an <u>independent variable</u>, and lying within a <u>normally distributed population</u> (refer to the results of statistical analysis). The general mean and standard deviation values representing each parameter are listed in Tables 3.1 and 3.2 according to the building location. These overall values were assumed to be the best estimated figures because they were obtained from the population of all collected data. In Equation (4) of Section 4.2.1, each of the four parameters were represented by x. Therefore it was required to predict the value of z from Equation (3). Y is a random value of c.d.f. of normal distribution which is supposed to be between 0 and 1. The range of values observed for Y from the overall population of each parameter was not exactly between the values 0 and 1. This would seem to rule out most practical applications since no real population is ever exactly normal. The set of the random values of Y was chosen therefore within the observed practical range, while the values outside this range were avoided by generating a new random value. this was due to the following reasons:

(a) If they were considered, the predicted value of the parameter will be out of the normal realistic range.

(b) An unrealistic accumulation will occur at the tails of the predicted frequency distribution of the parameter population if the generated random value of Y is assummed to be equal to the minimum or the maximum values of the observed range. For example, it was observed that the range of Y values of the arrival time in the morning was between 0.0044 and 0.99918 inclusive. If it was assummed that any generated value of Y less than 0.00441 should go to 0.00441 and similarly the values of Y greater than 0.99918 should go to 0.9918, this accumulation will occur.

Having generated the random value of Y, the value of z is calculated from the reverse of the c.d.f. of the normal distribution (reverse of Equation (3). The value of the random parameter x calculated from Equation (4) for the known overall mean and standard deviation values (Tables 3.1 or 3.2)). Thus the value of each of the four parameters was predicted. This process was repeated for each individual of the zone staff.

So far the arrival/departure times of each individual of the current simulated zone was known and it remained to identify the number of staff occupying the zone at each time interval (time step). A minimum time step of 5 minutes was thought to be fine enough for the purpose of the analysis because it was not practical in terms of computation time and results storage to predict the building energy requirements at time steps less than 5 minutes. Generally, time steps were available between 5 and 60 minutes in 5 minute increments. The time of the day (0-24 hours) was therefore classified to the required time intervals depending on the selected time step. The times of arrival/departure of each individual were compared with each time step of the day. If the time step fell within the period, the person existed in the building, code 1 (one) was assigned. If it was not, code 0 (zero) was assigned. Therefore a new pattern of these codes was obtained for each individual. Figure 3.2 could be imagined as patterns of codes 1 for the continuous lines and 0's for the spaces. The number of individuals occupying the zone at each time step was calculated simply by adding these codes in each time step. Table 4.7 illustrates the process for an hourly time step. This table is the equivalent of a three-dimensional array performing the process inside the computer program. Flowchart 4.2 shows the logic of the subroutine performing the simulation of staff patterns and defines their number in each time step of the day. The values of the sensible/latent heat emission per person and

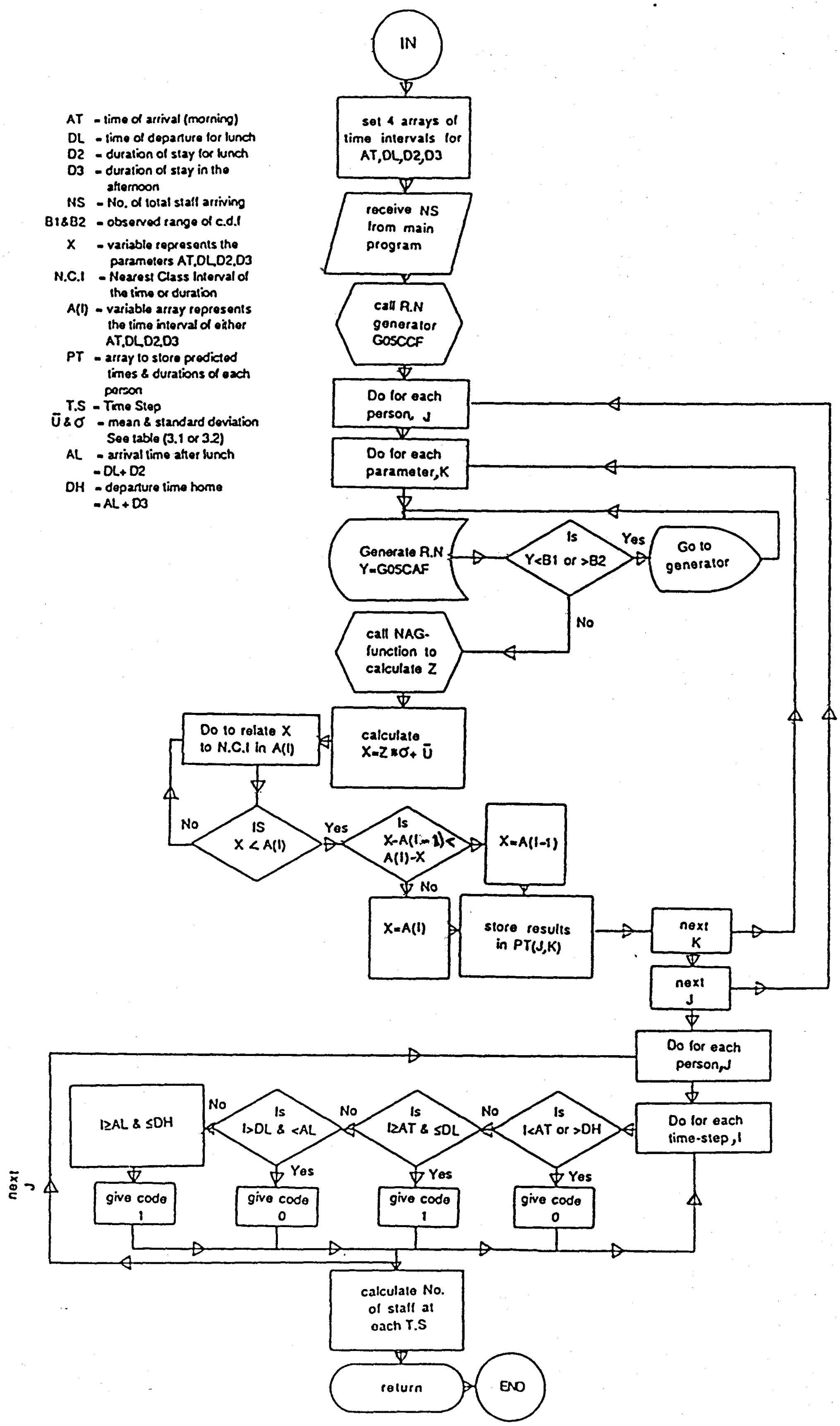
Table 4.7

The Process of Identifying the Number of People Occupying the Zone at each Time Step, Where the Total Number in This Example is 10

Person No.	Simulation time step or class interval																							
	0 ↓ 1	1 ↓ 2	2 ↓ 3	3 ↓ 4	4 ↓ 5	5 ↓ 6	6 ↓ 7	7 ↓ 8	8 ↓ 9	9 ↓ 10	10 ↓ 11	11 ↓ 12	12 ↓ 13	13 ↓ 14	14 ↓ 15	15 ↓ 16	16 ↓ 17	17 ↓ 18	18 ↓ 19	19 ↓ 20	20 ↓ 21	21 ↓ 22	22 ↓ 23	23 ↓ 24
1	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0
4	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	0
8	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0
Total Number	0	0	0	0	0	0	0	4	10	10	10	7	2	7	10	10	8	4	2	1	0	0	0	0

1 exists in the building

0 does not exist in the building



FLOWCHART 4.2

SUBROUTINE 'STAFF1' or 'STAFF2'

(simulation of staff patterns and profile) the convective/radiative splits were defined by the user of the program as they were dependent on the rate of activity. The total convective sensible, radiative sensible and the latent heat gains were calculated at each time step in the main program by multiplying these values by the number of staff.

4.4 PREDICTION OF VISITORS PATTERNS

The distributions that have been described for the samples of the visitors arose from discrete populations. The identification and fitting of the visitor model was based essentially on an empirical process, and was considered as being informative on the underlying probabilistic structure of the situation. The objective was simply to match the shapes of the data as accurately as possible. It was indicated earlier that the duration of stay of the visitor was dependent on his time of arrival, "the earlier the time of arrival, the longer the duration of stay". This implied that the model should take this relation into consideration and cope with it in a suitable manner. On the other hand there was no observed daily or seasonal variation, so that the prediction of the visitor pattern depending on the data of the overall population was assumed to be valid any day of the year.

As mentioned earlier, the destination of the visitor (zone to be visited) was not available, consequently, the variation of vistors patterns between building department was not explored. Therefore it was assumed that visitors' patterns in each zone of the building were not significantly different from the pattern of the overall population. This assumption had the advantage of keeping the model general rather than specific.

A visitor pattern was simulated by predicting the time of arrival first, while the duration of stay predicted depended on the time of arrival. The process of predicting each parameter in turn is explained as follows:

A - Predicting the time of arrival:

The probability f(x) of a visitor arriving at a particular time of the day is defined as the observed number of visitors (x_p) arriving at this time divided by the total number of visitors (n).

$$f(x) = \frac{x_p}{n}$$

On those grounds, the probablity of arrival at each time step could be calculated by setting a frequency table (histogram) for the data of overall population at a suitable class interval. A histogram at a class interval of five minutes was intended first, however this was found to be too unwieldy for practical use. As a result a 10 minute class interval was selected. From the histogram, the number of visitors arriving at each class interval was identified and the probability of arrival therefore calculated. The cumulative density function (c.d.f.) of this distribution was integrated and it was rising discontinuously from zero on the left of the range to unity on the right of the range. See Figure 4.3 and Table A1 of the Appendix. The c.d.f. is regarded as another method of representing a probability distribution. Instead of speaking of the probability that a random variable has a particular value, it is referred to as the probability that is less than or equal to a given value. The concept of the inverse of c.d.f. was used here again to predict the time of arrival of the visitor. That was done by generating a random value of c.d.f. from the NAG-subroutine G05CCF and the function G05CAF. The generated random value of c.d.f. was compared with the values of c.d.f. of Table A1 above and was related to the nearest one (the nearest class interval). Hence the midpoint value of arrival time which belonged to this c.d.f. was predicted. For example, consider a random value of 0.235. From Table A1 this value is closer to 0.249869 therefore the time of arrival associated with this value is 8.25 hrs. For the same reasons mentioned in Section 4.3, any generated value below 0.00561 (first value of c.d.f. in Table A1) was rejected and a new random value was

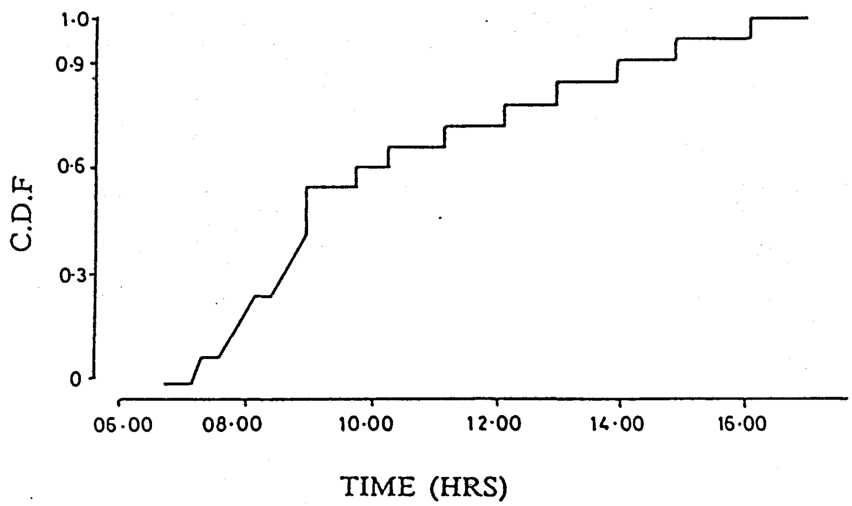


FIG. 4.3

Cumulative Frequency Diagram for the Visitors' Arrival Times generated.

B - Predicting the duration of stay:

An approach to the problem of dependence between the duration of stay and the time of arrival was achieved by assigning a group of durations to a suitable group of arrival times. That was done by sorting the time of arrival of the overall population from the first arrival to the last one keeping the departure time of each person the same (as shown in Fig 3.3). The duration of stay was calculated then by subtracting the time of departure from the time of arrival. These dependent durations were classified into five groups, each one belonging to a certain range of arrival times as follows:

Group one: arrival times between 06.45 and 09.00 hrs. inclusive

Group two: arrival times between 09.05 and 10.35 hrs. inclusive

Group three: arrival times between 10.45 and 12.05 hrs. inclusive

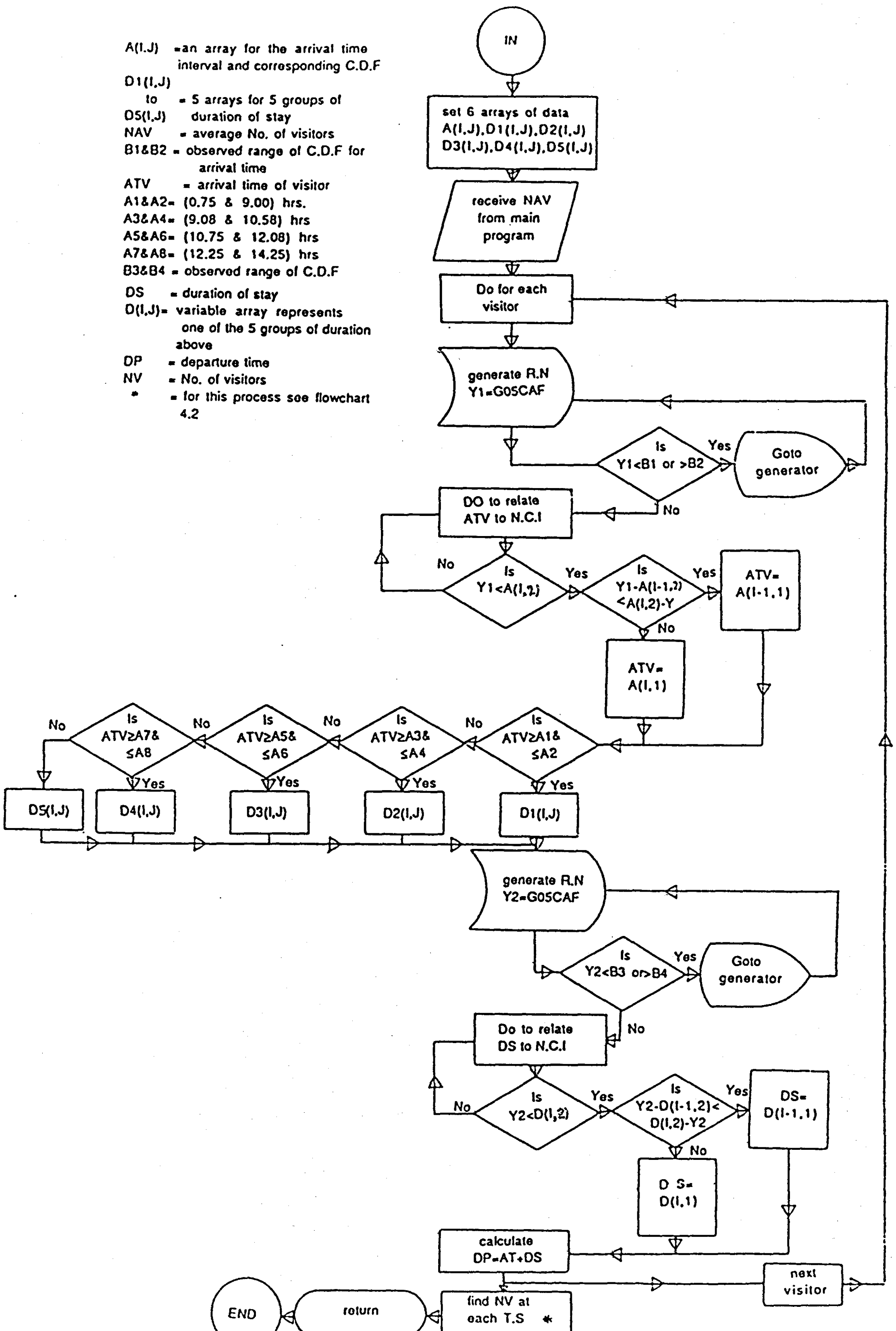
Group four: arrival times between 12.15 and 14.15 hrs. inclusive

Group five: arrival times between 14.25 and 16.45 hrs. inclusive

A Frequency Table like Table A1 has been set for each group, and the c.d.f. of these durations was calculated. See Table A2, A3, A4, A5 and A6 of the Appendix.

The simulated time of arrival was related to the right group and from this group a random duration was simulated by following the same procedures. The time of departure was then calculated by adding the duration of stay to the time of arrival. The process of predicting a visitor pattern was repeated for each visitor of the zone. The number of visitors occupying the zone at each time step was identified by using the concept introduced in Table 4.7. Flowchart 4.3 shows the logic of the simulation process to find the number of visitors occupying the zone at each time step. Thereafter these were passed from the subroutine to the main program in order to calculate the heat emission.

A(I,J) = an array for the arrival time interval and corresponding C.D.F
D1(I,J) to D5(I,J) = 5 arrays for 5 groups of duration of stay
NAV = average No. of visitors
B1&B2 = observed range of C.D.F for arrival time
ATV = arrival time of visitor
A1&A2 = (0.75 & 9.00) hrs.
A3&A4 = (9.08 & 10.58) hrs
A5&A6 = (10.75 & 12.08) hrs
A7&A8 = (12.25 & 14.25) hrs
B3&B4 = observed range of C.D.F
DS = duration of stay
D(I,J) = variable array represents one of the 5 groups of duration above
DP = departure time
NV = No. of visitors
* = for this process see flowchart 4.2



FLOWCHRT 4.3

SUBROUTINE 'VISITOR'

(simulation of visitor patterns and profile)

4.5 OCCUPANCY AT THE WEEKEND

It was observed from both analyzed buildings that there was no data about the people arrival/departure times during the weekend. It seems that this is the case in most office buildings since the weekend is regarded as an official holiday. Even if there was some of the staff working extra time over the weekend, there was no available information about their arrival or departure. For that reason it was not possible to simulate patterns of the movement of people during this period. However to make the model complete and to provide the possible flexibility of accounting for this problem, it was assumed that the staff profiles working over the weekend were following a simple constant profile. Their number was a percentage of the total number of the staff starting and ending time of occupation and were left to be decided by the designer. The heat emission was calculated simply by multiplying the values of sensible and latent heat by the number of the staff existing in the zone during the occupation period.

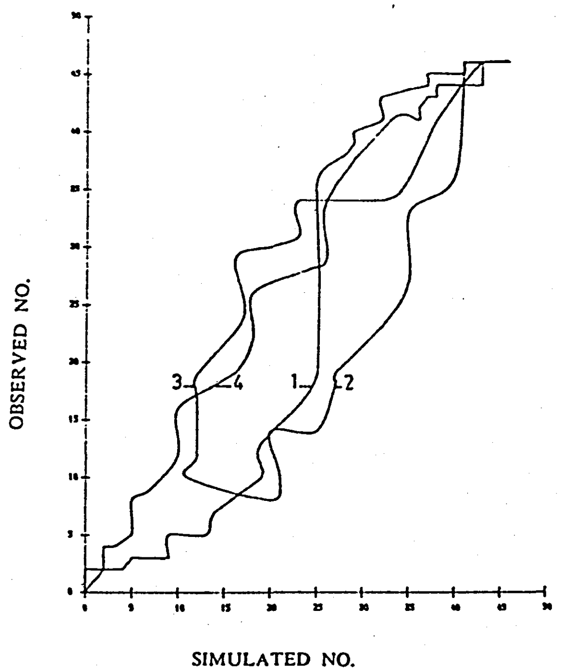
4.6 RESULTS AND DISCUSSION

At this stage the model for predicting occupancy patterns was completed and the following stage was to test its results by comparison with the available data. The adopted method of testing was to allow the model to predict occupancy patterns in different departments chosen from both analysed buildings. The results for each predicted parameter (i.e. time of arrival/departure or duration of stay) were compared with the available data of the corresponding parameter, to check how significant the differences were. The results were compared also with the pooled data (the overall population data) to check the reliability of the model. The outcome from these comparisons have shown the following aspects:

(a) The predicted frequency distribution of the population of each parameter agreed with the observed frequency distribution of corresponding parameters (normal distribution for the staff parameters and discrete for the visitor parameter).

(b) The mean and standard deviation values of the population of each parameter were not significantly different from the values of corresponding parameters of the available data. It is worth emphasizing that the random process adopted in the model reflected the realistic variation in the occupancy patterns and hence their exising number inside the zone. This daily variation was, in fact, due to the changing number of absences and the random arrival/departure time of the building's occupancy. Figure 4.4 shows that the predicted number of the staff of department 1 of the Scottish Assurance Society at any time during working hours is not significantly different from the observed number at the same time. This figure was plotted in 5 minute time steps and for one day. It shows four non-straight lines where the first line represents the relation between the observed and predicted number at the period of arrival in the morning where the number of staff are increasing from zero to the total number (46). The second line represents this relation during the period of departure for lunch where the number of staff decreases to the minimum number (11) i.e. the space did not become empty due to the overlap occuring in this period. The third line represents this relation at the period of arrival after lunch where the number of staff increases again to the total number (46). The fourth line represents this relation when the number of staff decreases from the total number to zero at the period of departure home. The regression equation between the observed and the predicted number is shown on Figure 4.4.

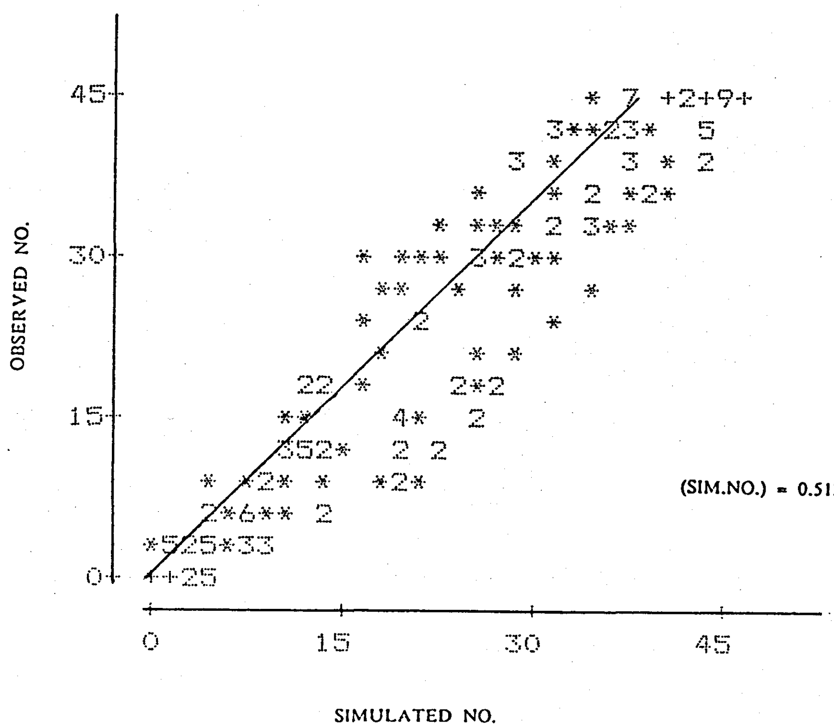
Figure 4.5 shows the stochastic process which was adopted in the model and the closeness of the relationship between the predicted and observed numbered compared with a reference line (reference line is the straight line plotted at 45° which represents the case when the



(SIM. NO.) = 0.398 + 0.93 * (OBS. NO.)

FIG . 4. 4

A COMPARISON BETWEEN THE OBSERVED AND PREDICTED NO. OF STAFF IN 5 MINUTE TIME-STEPS FOR 1 DAY

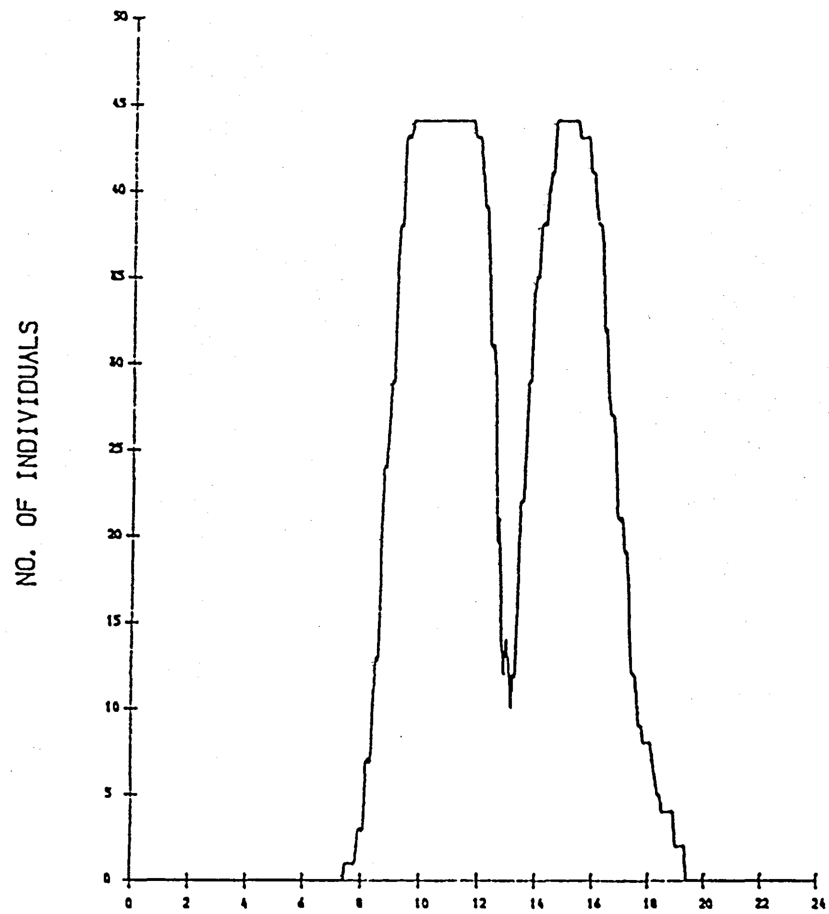


(SIM.NO.) = 0.512 + 0.95 * (OBS. NO.)

FIG. 4.5

A COMPARISON BETWEEN THE OBSERVED AND PREDICTED NO. OF STAFF IN 5 MINUTE TIME-STEPS FOR 2 CONSECUTIVE DAYS predicted number equals the observed number). The regression equation on this figure implies that the difference between the predicted and observed numbers is not significant. However the small difference reflects the realistic variation from one day to another since this figure was plotted in 5 minute time steps for 2 consecutive days.

(c) The predicted profile of the people occupying the zone during the day has shown an agreement with the observed profile. A predicted profile for the occupancy of department 1 of the Scottish Assurance Society is presented in Figure 4.6. A comparison between this profile and the observed profile of this department which was presented in Figure 3.5 shows that they are behaving in the same manner. The general shape of both profiles is the same while the slight difference in the flow of the profiles and the minimum number of people occupying the zone during lunch was due to the realistic random process suggested here. The important aspect observed here is that the shape of the profiles presented in both figures generally characterized the departments of both analysed buildings. Therefore, it is suggested that the profile presented in Figure 4.6 is representative of a general case of an office building running a flexi-time system.



TIME (0,24) HRS.

FIG . 4. 6

THE PREDICTED PROFILE OF THE STAFF OF DEPT . 1

REFERENCE

[4.2.1] G Barrie Wetherill, Elementary Statistical Methods, 3rd edition.

5. *STOCHASTIC SIMULATION OF ARTIFICIAL LIGHTING USE AND THE RESULTANT HEAT EMISSION*

5.1 INTRODUCTION

The main intention in this chapter is to develop the use of occupancy patterns in assessing the use of artifical lighting in relation to daylight levels and type of control. The probability of switching the artificial lighting in zones controlled by manual or localized switching was presented by BRE from field studies. This probability was used in this analysis to estimate switching on the artifical lighting in a particular space depending on the level of daylight available in the space. A stochastic process has been adopted to model the activity of switching the artificial lighting on for certain values of the probability of switching. The estimation of lighting use controlled automatically by photo-electric cells is presented also. A further comprehensive discussion of each factor considered will follow.

5.2 ESTIMATION OF DAYLIGHT

The quality and intensity of daylight varies with latitude, season, time of day and local weather conditions. For daylight design in the UK the overcast sky luminance distribution has traditionally been used. This means that it cannot account for the effects of orientation which occur on non-overcast days. Generally, the overcast sky should be recognised as a "worst case", modelling daylight availability on dull days.

BRE field studies have shown that the probability of switching on artificial lighting on entering a space correlates closely with the daylight availability at the time but switching off rarely occurs until the last occupant has left (see 5.3). For the estimation of daylight, the hourly mean diffused values of daylight shown in Table 5.1 were used to evaluate the daylight at any time of the day. These values are based on measurements made by the Meteorological Office at

TABLE 5.1 Mean diffuse illuminance at Kew (all values in KLUX)
See Fig. 5.1

Month	Time of day																	
	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21
Jan					0.3	2.2	5.8	8.7	10.2	10.1	8.9	6.0	2.5	0.3				
Feb				0.2	2.0	6.5	10.6	14.0	15.3	15.9	13.7	10.9	6.7	2.0	0.2			
Mar			0.2	2.2	7.3	12.5	17.1	20.7	22.5	22.4	20.4	16.8	12.5	7.4	2.3	0.3		
Apr		0.3	2.1	7.3	12.6	18.2	22.7	26.1	27.7	27.6	26.6	24.0	18.7	13.4	7.6	2.1	0.3	
May	0.2	1.6	6.8	13.0	19.3	24.7	28.7	31.0	33.6	33.8	32.6	29.1	24.4	18.9	13.2	6.5	1.6	0.1
Jun	0.3	3.3	9.0	15.1	20.9	26.0	30.6	32.6	34.8	35.4	34.0	30.2	25.6	20.5	14.8	9.1	3.3	0.3
Jul	0.1	2.1	7.4	13.9	20.0	26.1	31.1	34.9	36.3	35.9	34.2	31.1	26.6	20.7	14.6	8.1	2.3	0.2
Aug		0.5	3.7	9.9	16.6	22.6	26.9	30.6	32.9	33.1	31.8	28.3	23.1	17.0	10.5	3.8	0.5	
Sep			0.7	4.5	11.0	16.9	22.2	25.0	25.9	25.4	24.5	21.1	16.2	10.5	4.3	0.7		
Oct				0.7	4.2	9.4	13.8	17.1	18.7	19.0	17.1	14.0	9.8	4.2	0.7			
Nov					0.7	3.8	7.8	10.9	12.6	12.6	11.0	8.2	3.9	0.6				
Dec					0.1	1.6	4.7	7.6	9.0	9.1	7.7	4.9	1.6	0.1				

Note: Blank spaces indicate means of less than 0.1 klx

Reference [5.2.1]

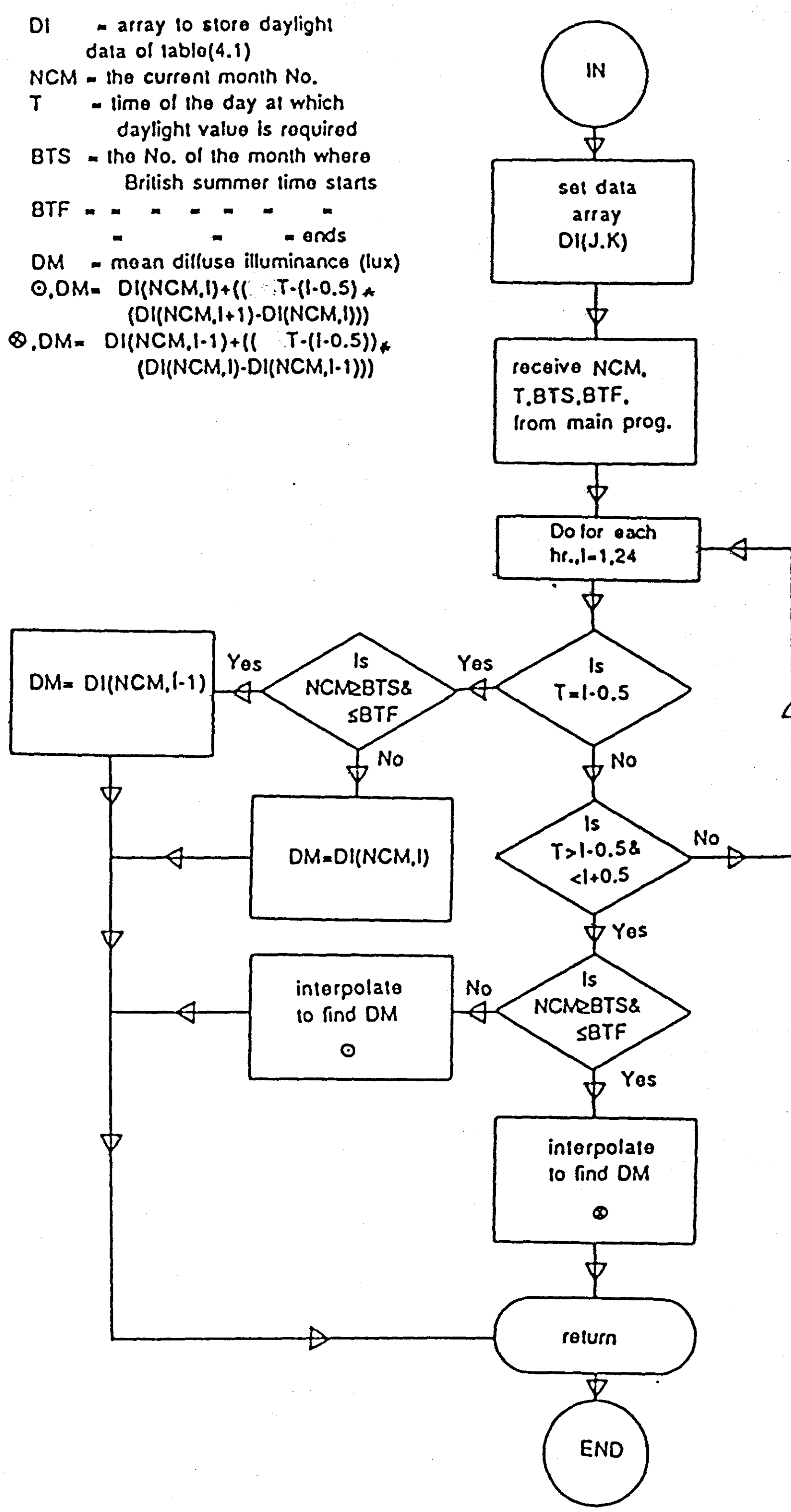
Kew. [5.2.1]. For time steps less than hourly, linear interpolation has been used. This Kew data was used because the climatic data for the same location was available on ESP to estimate building energy requirements. The BST (Local Apparent Time + 60 minutes) was taken into consideration and, for flexibilty, the months of BST were left to be decided by the designer. A computer subroutine was written to perform the process of estimation and return the value of daylight in "lux" at the required time-step. The logic of the subroutine is shown in Flow Chart 5.1. It is worth mentioning that a more realistic approach could have been adopted if the basic daylight data was available for each month of the year in the form presented in Table 5.2. A stochastic technique could be used then to predict the value of daylight according to the probability of occurance of that value at a certain time of the day. Unfortunately the basic data was available only for the month of April. For that reason, the mean hourly values of daylight tabulated in Table 5.1 were used.

In the following sections the concept of predicting artificial lighting use according to the type of control will be explained in detail taking into consideration the predicted patterns of people presented in the previous chapter and the availability of daylight in the building

5.3 MANUAL LIGHTING CONTROL

The field-work carried out at BRE in recent years on traditional manual control of general ceiling mounted lighting [5.3.1] and [5.3.2] has resulted in a model of occupant behaviour with respect to switching use in multi-occupant spaces [5.3.3] and strongly suggests a general philosophy of lighting control which will lead to energy savings.

Hitherto, estimation of lighting use for, say, an office space, has been based on very crude assumptions [5.3.4]: either that all lighting is in use for the occupied period, or that occupants control their lighting as if they were photo-electric cells. The former assumption results from the not inconsiderable



FLOWCHART 5.1
SUBROUTINE 'DAYLIT'
(estimation of daylight)

Table 5.2 Example of table of basic daylight data (diffuse illuminance for April measured at Bracknell)

NORMALISED FREQUENCY DISTRIBUTION OF HOURLY MEANS OF DIFFUSE ILLUMINANCE ON A HORIZONTAL SURFACE

(NORMALISATION GIVES THE AVERAGE NO OF DAYS IN THE MONTH HAVING A GIVEN RANGE OF DATA VALUES FOR EACH HOUR)

BRACKNELL APRIL (1964-1973)

TIME INTERVAL (L.A.T.)

INTERVAL (KLUX)	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
0-0.1	30.00	30.00	30.00	30.00	11.95	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.31	11.65	30.00	30.00	30.00	30.00
0.1-0.2					0.39	0.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.73	7.93				
0.2-0.3					3.05	1.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.26	4.96				
0.3-0.4					3.56	0.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.05	2.96				
0.4-0.5					2.29	1.57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.64	1.98				
0.5-0.6					0.76	1.99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.64	0.50				
0.6-0.7						0.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.26					
0.7-0.8						0.72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.65					
0.8-0.9						1.65	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.63					
0.9-1.0						1.52	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.21	1.26					
1-2						7.97	1.67	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.36	8.18					
2-3						4.51	3.01	0.52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	1.36	5.45					
3-4						2.54	2.80	1.04	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.21	0.83	2.51	3.25					
4-5						1.57	2.00	1.04	0.31	0.10	0.0	0.0	0.0	0.0	0.31	0.21	0.93	2.72	1.69					
5-6						1.68	1.66	1.66	0.83	0.10	0.10	0.0	0.0	0.21	0.41	0.21	0.72	2.51	1.89					
6-7						0.52	2.39	0.93	0.21	0.0	0.0	0.0	0.10	0.10	0.10	0.52	0.93	2.26	0.10					
7-8						0.10	2.39	0.73	0.73	0.31	0.10	0.0	0.10	0.0	0.21	0.62	1.14	2.62						
8-9							1.66	1.45	0.31	0.42	0.42	0.21	0.31	0.10	0.31	0.52	0.72	2.72						
9-10							3.43	1.04	1.04	0.31	0.10	0.10	0.10	0.31	0.72	0.83	1.14	3.24						
10-15							7.27	7.59	5.42	3.32	1.00	1.67	1.35	2.40	1.06	3.54	9.41	7.03						
15-20							0.83	8.82	4.56	3.22	2.72	1.66	2.92	2.08	3.61	6.98	9.82	0.63						
20-25								4.36	8.23	4.07	2.02	4.26	3.23	4.17	6.34	6.65	3.72							
25-30								0.31	4.46	6.05	6.27	3.43	4.48	5.21	6.49	5.10	0.52							
30-35									1.98	4.58	5.96	6.54	5.52	6.25	5.26	2.19								
35-40									1.25	3.22	5.02	4.36	5.31	5.10	2.60	0.21								
40-45									0.21	1.66	2.20	4.67	4.48	2.56	1.24									
45-50										0.73	1.68	1.66	1.04	1.15	0.21									
50-55										0.10	0.31	0.73	0.73	0.42										
55-60											0.21	0.31	0.21											
60-65												0.21	0.10											
NUMBER OF OBSERVATIONS USED:	0	0	0	0	118	286	289	289	288	289	287	289	286	268	291	286	290	287	206	121	0	0	0	0
NUMBER OF HOURS POSSIBLE: (SEE FOOTNOTE)	0	0	0	0	120	300	200	300	300	300	300	300	300	300	300	300	300	300	300	128	0	0	0	0

DATA ARE CONSIDERED FOR EACH HOUR DURING WHICH THE SUN WAS ABOVE THE HORIZON FOR ANY TIME

Reference [5.2.1]

anecdotal evidence that people never switch lights off and the latter reflects expected requirements rather than an expression of anticipated behaviour.

The BRE results have shown that both assumptions have some basis in observed behaviour. In summary the very detailed studies carried out using time lapse photography [5.3.5] and [5.3.2] in a number of different installations with different lighting design levels, different occupants and different window sizes and orientations, show that:

(a) Usually either all or none of the lighting was in use - it was rare for only part of the lighting to be on.

(b) The occupancy cycle of the space determined when people switched the lights on and off. Lights were switched on (if needed) when people entered a space, but rarely switched off until the space had become completely empty. Thus in continuously occupied spaces, such as multi-person offices, switching was generally confined to the beginning and end of the working day. By contrast, in intermittantly occupied spaces, such as school classrooms, switching occurred throughout the day.

(c) The probability of people switching on artificial lighting in a daylit space at the beginning of a period of occupation, was closely related to the minimum working area daylight illuminance.

These results were obtained from studies in multi-occupant spaces with traditional switching arrangements i.e. a panel of wall mounted switches located by the entrance to the space. The inference to be drawn is that a decision - conscious or subconscious - is made about the adequacy of daylighting on entering a space and lighting is switched accordingly. For the switching arrangements encountered, daylight adequacy was judged, apparently not by appearance of a particular occupant's desk space, but was best correlated with the worst daylit area in the room as in (c) above.

The probability of someone turning artificial lighting on is illustrated by Figure 5.2, reference [5.3.2] and the fitted curve equation:

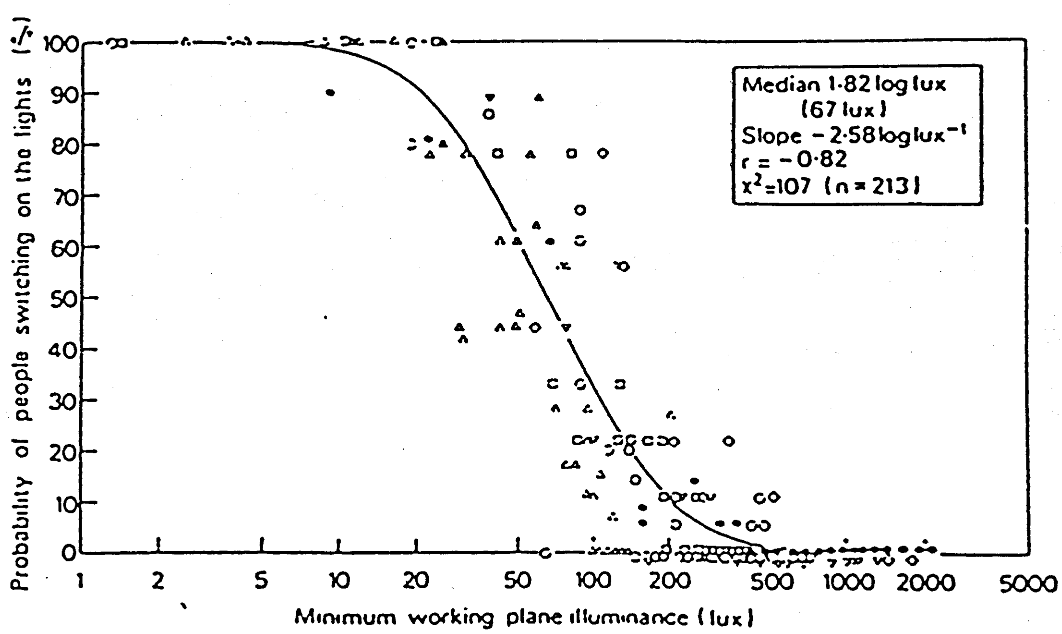


Fig. 5.2 Probability of people switching on lights in relation to minimum daylight illuminance on the working plane. Reference [5.3.2]

$$y = a + c/(1 + \exp\{-b(x-m)\}) \qquad \text{.................. (1)}$$

where

y = switching probability
a = -0.0175
b = -4.0835
c = 1.0361
m = 1.8223
x = $\log_{10}$ (minimum daylight illuminance level in the working area, lux)

As indicated earlier, in the continuously occupied spaces (offices), the lighting tended to be either on or off for the whole of the working day. In flexible working hours it meant that the multi-person office was occupied by at least one person continuously for periods up to 12 hours. Under these circumstances it was observed that the switching activity was generally confined to the beginning and end of the working day. The accumulative probability curve presented in Equation (1) was constructed by assuming that during normal working hours the zones of an office building were never completely empty. Thus the daylight level for periods during normal working hours when the artificial lighting was off can be regarded as the level at which the occupants made a choice not to switch on the lights. This study covered a period of 6 months [5.3.2]. In this chapter, models have been developed to predict the daily lighting use in relation to the building occupancy (presented in the previous chapter) and the type of control. A stochastic process was included to predict the switching on activity. The logic of the modified model which simulates the lighting use for any zone of the building on a particular day was constructed as follows:

(1) The occupancy cycle of a zone in the building started at the time of the first arrival to the zone and ends at the time of the last person to depart home. If the space became empty during the lunch period (this rarely occurred and only in zones with a very low density of occupancy) then two switching periods occurred, one, by the first arrival in the morning and the other one by the first arrival after the lunch period. The lighting is assummed to be switched off in both periods by the last

individual who leaves the space as in (b) above. It is worth mentioning that if the space became empty at lunch time, then the probability of switching the light on by the first arrival after lunch is low because the daylight had improved significantly. The probability of switching the light on at the beginning of the occupation period (by the first arrival) is calculated according to the daylight illuminance at the darkest point in the working area. See Equation (1). The illuminance at the darkest point in the working area was calculated by the following Equation (2) [5.3.3]:

$$EINM = DMILL \times ORN \times MDF/100 \qquad \text{.....................(2)}$$

where

EINM = Minimum daylight illuminance in the working area (lux)

DMILL = External diffused illuminance (lux)

ORN = Orientation factor

MDF = Minimum daylight factor in the working area (percent)

The values of external diffused illuminance was defined from Table 5.1 as explained in Section 5.2. The orientation factor is a correction factor in order to account accurately for the orientation of windows and given as:

= 1.2 for south-facing windows
= 1.04 for east-facing windows
= 1.00 for west-facing windows
= 0.77 for north facing windows

The minimum daylight factor in the working area is the ratio of indoor to outdoor daylight illuminance under the standard overcast sky. See Equation (2). This value varies from one zone to another according to the design of the building and its surroundings, so that it has to be known for each zone of the building. Since the probability of switching was calculated for each simulated day, it is important to mention that the value of the probability was varied between the days of the same month although the daylight data used for each day was the mean hourly values of that month. (See Table 5.1). That was due to the variation of the daylight data taken at the time of the first arrival (ie the time of the first arrival to the zone varies from one day to another within the range of maximum 30 minutes). For example the probability of switching at 07:30 hrs by an arrival on a February day was 90% (for a minimum daylight factor value of 1%) while it was 70% if the first person arrived at 08:00 hrs. The case in summer is not as significant as in winter. For example if the first arrival to the same zone was at 07:30 hrs in June, then the probability of switching the light on was 10% , whereas if the first arrival time was 08:00 hrs, then the probability of switching was 8%. Generally if the mean value of the probability of switching the light on in say, winter, was 80% then it was expected that out of 100 days the lighting was switched on for 80 days.

(2) Having defined the probability of switching on a particular day, the switching on activity was predicted by adopting a stochastic process. That was by generating a random value between the values of zero and one by using the NAG-subroutine G05CCF. The main characteristics of the random number generator was that the probability of generating a random value between zero and one was 100%. The probability of generating a value equal to or less than, say, 0.3 is 30% and so on. The generated value was referred to as the probability that it is less than or equal to a given value. Thus if the value of the probability of switching was say, 30%, then a random value was generated between the values 0 and1; if it was equal to or less than 0.3, then all the lighting was switched on ((a) above) and remained on all of the occupation period ((b) above), otherwise it was off all day.

In this way the lighting use in any zone of the building was predicted.

(3) If the lighting of the zone was on, then switching off activity was assumed to be performed by the last person leaving the zone ((b)

above). The time of the last person departing the zone was defined from the occupancy patterns and hence the light regarded as switched off at this time.

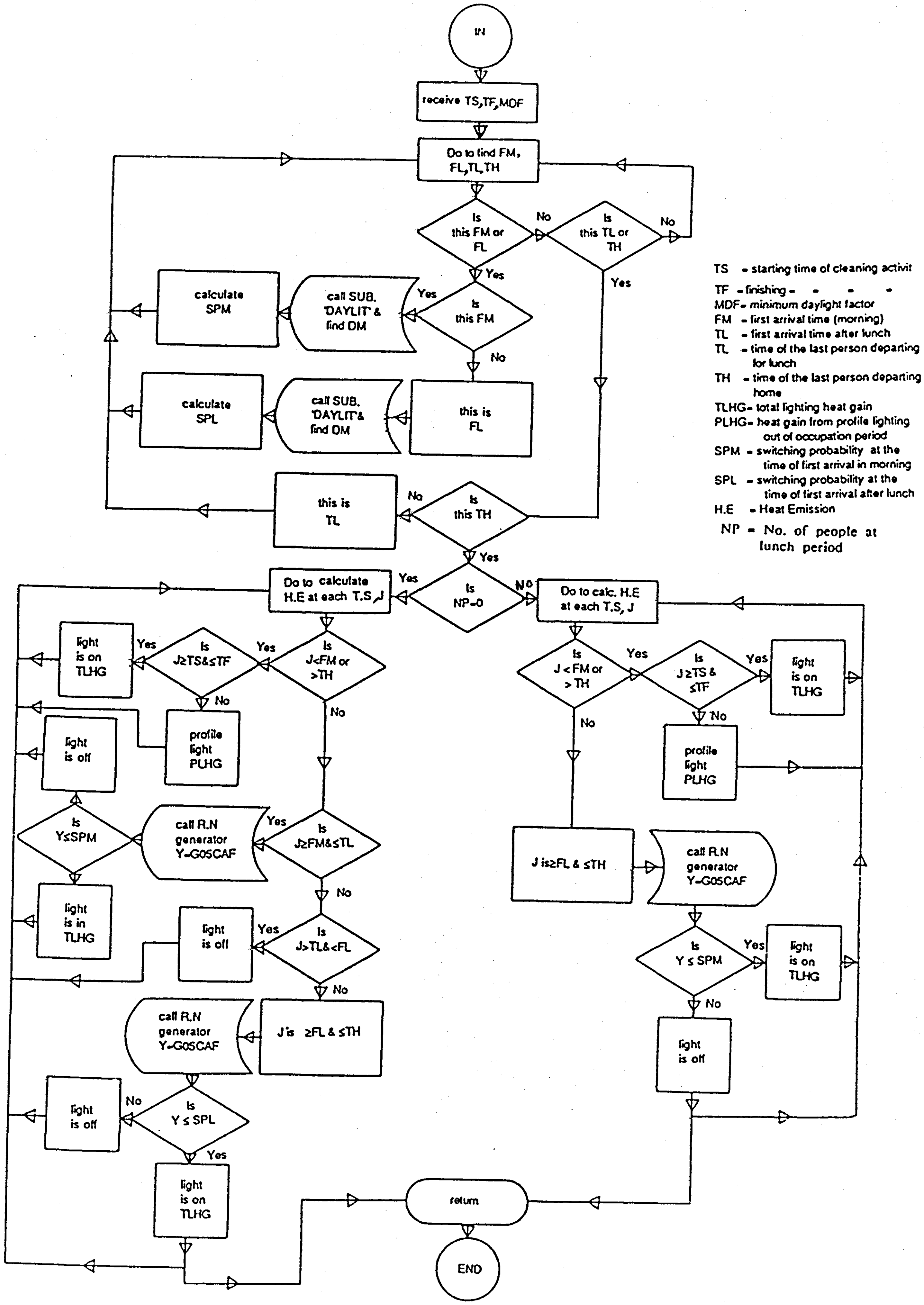
(4) The security lighting profiles for each zone of the building at periods out of occupation was left to be chosen by the designer as a percentage of total lighting.

(5) The period of cleaning activity was assumed to be performed at times out of the occupation period (as normally observed) and since cleaning normally requires the maximum possible lighting it was reasonable to assume that all the lighting was in use during this activity.

(6) The heat emission from lighting was calculated at each time step of the day (0-24 hrs) according to the lighting use as explained above. The time step was the same as that used for predicting heat emission from occupancy. The values of sensible heat emission and the radiative/convective splits were to be given by the designer, according to the type of light fittings. A subroutine of a computer program was written to predict the lighting use control by manual on/off switching. The logic of this subroutine is shown in Flowchart 5.2.

5.4 LOCALISED LIGHTING CONTROL

In the previous section, the discussion has been almost exclusively restricted to general ceiling mounted lighting - the predominant interior lighting design solution for many years. Recently there has been new interest in task/ambient or local/background lighting for offices [5.4.1] [5.4.2] but it is not immediately clear how such installations should be controlled. The temptation is to treat the ambient or background lighting in the same way as general lighting and leave the task lighting totally to the occupants. Control strategies were suggested by Crisp and Henderson



FLOWCHART 5.2

SUBROUTINE 'MANCNT'
(simulation of lighting use controlled by traditional manual switching)

[5.3.4] and were applied in different types of installations which have day lighting taking into account work-related aspects of occupation. Hence if the switching arrangements for the space are made more localized, i.e. distributed throughout the room (in particular controlled by pull cords or table lamps) and related sensibly to local areas served, it can be hypothesised that local switching will be related to 'local' worst daylit areas rather than a 'whole space' worst daylit area. Necessarily this means that, on average, lighting will be less likely to be switched on and it is quite possible that the flexibility and convenience generated for the user may further result in some switching off. Moreover because the case dealt with was associated with localized lighting provided for each individual, (i.e. each individual was provided with a pull cord or a table lamp), then it was expected that the probability of a particular individual switching on the local or desk light was much lower at the arrival time after lunch than it was at the arrival time in the morning because the daylight had improved significantly. Hence the average lighting use will be less when compared with manual switching arrangements. It is, of course, extremely difficult to estimate precisely the lighting controlled by localised switching arrangements since a detailed daylight distribution and individual occupancy pattern would be required. Even if the second was defined clearly, the first would still be difficult to estimate. It could be assumed therefore that the general behavioural model which is related to 'whole space' worst daylit areas would be applied on a local basis. (Evidence that it does is given by a study [5.4.3] of an installation with localised switching where local illuminance levels for switching compare favourably with those obtained in the BRE work). Hence the use of the lighting associated with each individual could be predicted and a stochastic process could be adopted in the same way presented in the previous section. The logic of the prediction process for a particular zone on a particular day would be summarized as follows:

(1) In this stage the occupancy patterns were defined for each zone of the building as explained in Chapter 4. The simulation of the lighting use for any individual was performed by defining the probability of switching in the morning from Equation (1) of Section 5.3. At the time of arrival in the morning the minimum working plan illuminance was calculated by Equation (2) of Section 5.3 at known values of external daylight (see Flowchart 5.1), minimum daylight factors and the orientation factor.

(2) Having defined the probablity of switching in the morning, the switching on activity was predicted by generating a random cumulative number (as explained in (2) of 5.3). If the generated random number was equal to or less than the probability of switching, then the light associated with the current individual is switched on, and remains on till the time of departure for lunch (all morning duration). (See (b) of Section 5.3). If the lighting was on, then the heat emitted from this light was calculated for each time step within the morning duration and stored in an array.

(3) For the duration of lunch, of any individual, the light was assumed to be off and the heat emitted was zero.

(4) At the time of arrival after lunch, the probability of switching was evaluated also, (it is normally lower than the probability of switching in the morning because the daylight has improved), a random number was generated also to predict if the lighting was on or off. If the light associated with this individual was on then it remains on all the afternoon duration of the current individual and will be switched off at the departure time. The heat emission was therefore calculated for time step within the afternoon duration and stored in the same array.

(5) This process was repeated for the lighting associated with each individual of the current zone, and hence the values of the heat emission from the lighting of all individuals was added together for each time step by using the concept introduced in Table 4.7.

(6) Since the background lighting is normally provided to achieve certain

visual requirements in particular parts of the zone where it is needed, then it was reasonable to assume that this lighting is always on during the occupation period. Hence the heat emission from this lighting could be evaluated at each time step within the occupation period and added to the task lighting at the same time step.

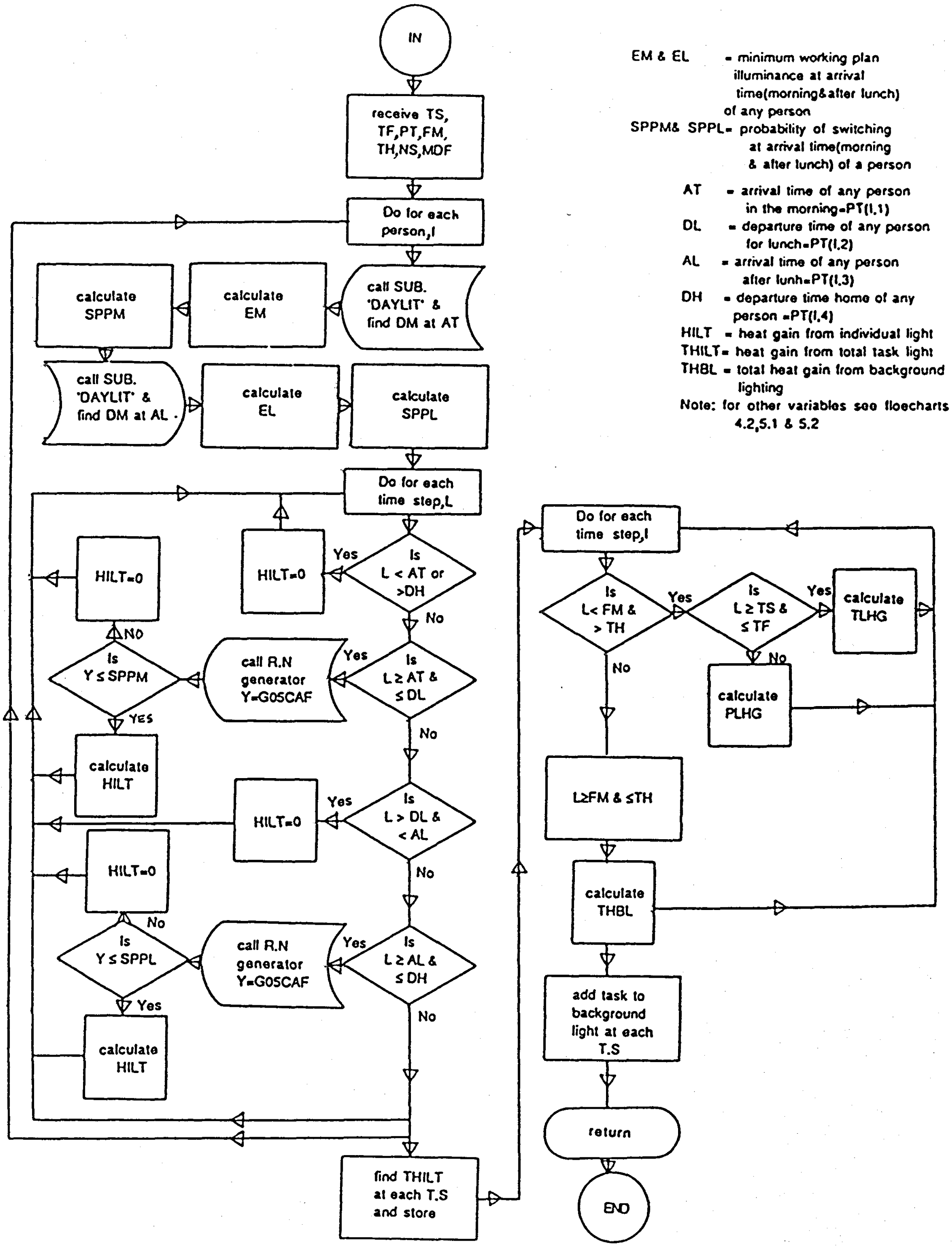
(7) The security lighting or the lighting used out of the occupation period was assumed to be part of the general background lighting and as a percentage (0 to 100%) of the total because both are required for the same purposes. The heat emission from this lighting was calculated for each time step within this period.

(8) For the simulation of the heat emission from lighting during cleaning activity, it was assumed that all the lighting of the zone was in use. The heat emission at time steps within this period was calculated from the total lighting.

The process of predicting the lighting use controlled by localised switching arrangements performed by a subroutine of a computer program and the logic of this subroutine is shown in Flowchart 5.3.

5.5 PHOTOELECTRIC CONTROLS

Failure to switch off lights in areas receiving sufficent daylight is another major cause of energy waste. This can occur when the lights are switched on, say, at the beginning of the day when daylight alone is insufficient, and remain on when the daylight later provides more than the illuminance to which the artifical lighting was designed. Photoelectric control can ensure that the lighting cannot be turned on or remain on when the daylight provides the required illuminance by itself. Although such systems reduce the use of artificial lighting considerably, the photoelectric controls are not widely used in office buildings because they are expensive to purchase and install [5.3.4] and it is generally unacceptable to the building occupants [5.5.1]. The sudden changes of illuminance resulting from an of/off switch control, for example, may cause



EM & EL = minimum working plan illuminance at arrival time(morning&after lunch) of any person

SPPM& SPPL= probability of switching at arrival time(morning & after lunch) of a person

AT = arrival time of any person in the morning=PT(I,1)

DL = departure time of any person for lunch=PT(I,2)

AL = arrival time of any person after lunh=PT(I,3)

DH = departure time home of any person =PT(I,4)

HILT = heat gain from individual light

THILT= heat gain from total task light

THBL = total heat gain from background lighting

Note: for other variables see floecharts 4.2,5.1 & 5.2

FLOWCHART 5.3

SUBROUTINE 'LOCCNT'

(simulation of lighting use controlled by localised switching arrangment) visual problems for the occupants of the building. If the photoelectric control is required to be used in an office building, then it is possible to simulate the use of lighting controlled either by on/off, dimming or multi-control (on/off and dimming) systems when the space design illuminance is known. The heat emission from lighting according to its use can therefore be estimated. The simulation of lighting use controlled by each type of photoelectric control is explained below:

5.5.1 On/Off

Two basic forms of automatic photoelectric switching control can be used to link electric lighting use to daylight availability [5.5.1]. The cheaper method is to switch the lights by a photocell, mounted externally or facing out of a window to sense daylight only (open loop control). The use of an external sensor is not suitable where there are complex shadows across the facade. The alternative approach has the sensor mounted in the area to be controlled to sense both daylight and artifical light (closed loop control). In this case, a switch-on level and a switch-off level need to be set so that the activation of the electric lighting does not immediately cause switching off. For an office zone controlled by an on/off switch, it is reasonable to assume that the sensor is sensing the daylight at the worst working plan area [5.5.2] to ensure that when the daylight level at this area is equal to or greater than the design illuminance of the zone, then all the lighting will be switched off by the controller. Hence when it is needed to define the lighting use for a zone controlled by on/of photoelectric control on a particular day, then the procedure of the simulation could be summarized below:

(1) The photoelectric control system was assumed to start functioning at the beginning of the occupation period, and end at the end of the occupation period. This is a reasonable assumption since the waste of lighting occurs mainly during the occupation period. The occupation period starts at the first arrival time and ends at the last person departing home which

could be defined easily from the occupancy patterns model.

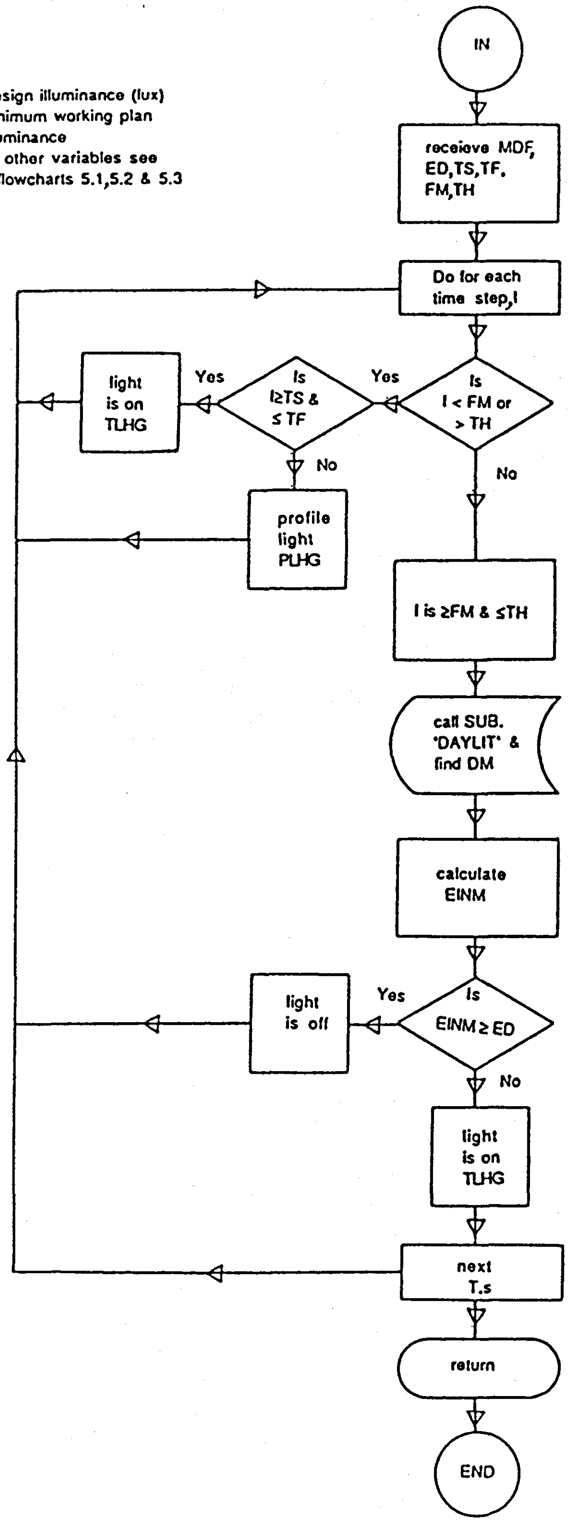
(2) To define if the artificial lighting is on or off at any time during the occupation period, it is required to estimate the minimum working plan illuminance at this time. That could be calculated by Equation 2 of Section 5.3 for the known value of external daylight, minimum daylight factor of the zone and orientation of windows. Then this value could be compared with the design illuminance of the zone, if it is equal to or greater than the value of the design illuminance, then all the lighting of the zone is off but if it less, then the lighting is on. This process could be repeated for each time step within the occupation period. It is important to indicate that in real life, the photoelectric switch device should allow a delay to be set so that after a switching action has occurred no further action can take place until after the set delay. This is to minimise the problem of rapid switching caused, for example, by fast-moving clouds. In this analysis this does not occur since the daylight data used in the simulation process were hourly mean values which increase and decrease linearly with time without taking into account a situation such as fast-moving clouds. See Table 5.1.

(3) The security lighting profile for each zone of the building at the periods out of occupation was left to be defined by the designer as a percentage of the total lighting.

(4) The period of cleaning activity was assumed to occur at a time out of the occupation period and left to be defined by the designer. All the lighting of the zone was assumed to be switched on at this period and usually by special switches overriding the photoelectric control system.

(5) The heat emission from lighting at each time step (0-24 hrs) could be calculated therefore according to the use of the lighting mentioned in (2) through (4) above at the known values of sensible heat and convection/radiation splits. Flowchart 5.4 shows the process of simulation for a zone controlled by on/off photoelectric control on a particular day.

ED = design illuminance (lux)
EINM= minimum working plan illuminance
Note: for other variables see flowcharts 5.1,5.2 & 5.3



FLOWCHRT 5.4

SUBROUTINE 'PONOFF'

(simulation of lighting use controlled by photoelectric ON/OFF)

5.5.2 Top-Up (Dimming)

Unlike switching, 'top-up' control ensures that at all times the sum of daylight and electric lighting reaches a given minimum (the design level). This is achieved photoelectrically by sensing the total light in the controlled area and automatically adjusting electric light output to 'top-up' to the set level. If the daylight alone is adequate then electric lighting is dimmed to extinction. The energy saving potential of 'top-up' control is greater than for on/off photoelectric switching and the mode of control likely to be more acceptable to occupants. However, although savings will be greater, costs are higher because of the more complex control electronics and special lamp ballasts required.

Photoelectric switching can be applied to a wide range of lamp types: for high intensity sources special ballasts may be required to minimize restrike times. Photoelectric dimming is most satisfactorily applied to flourescent lamps [5.5.3]. Although dimming of incandescent lamps presents no problem, the light output/power characteristics are such that energy savings are unlikely to be achieved cost effectively [5.5.1]. With incandescent lamps the rate of reductioin in light output is not proportional to the lamp power [5.5.2], while for flourescent lamps the power requirements is essentially linear with light output [5.3.4]. However, a clear relationship between the power requirement and the light output [equation or formula] is not available in the literature for either type of lamp. THORN LIGHTING LIMITED have suggested that the rate of reduction in light output of fluorescent lamps is linearly proportional to the lamp power reduction. Hence since the analysis deals with the lighting of an office building where the fluorsecent lighting is recommended, this relationship has been used in the simulation process.

The logic of the simulatiŏn process which was suggested for the on/off switching could be used here except that when the minimum working plan (EINM) (Equation 2 of section 5.3) was estimated at any time within the occupation period, it was compared with the value of design illuminance (ED) at each time step as follows:

(a) If it was greater than or equal to the design valuae, then the lighting was assumed to be dimmed to extinction and the heat emission to be zero.

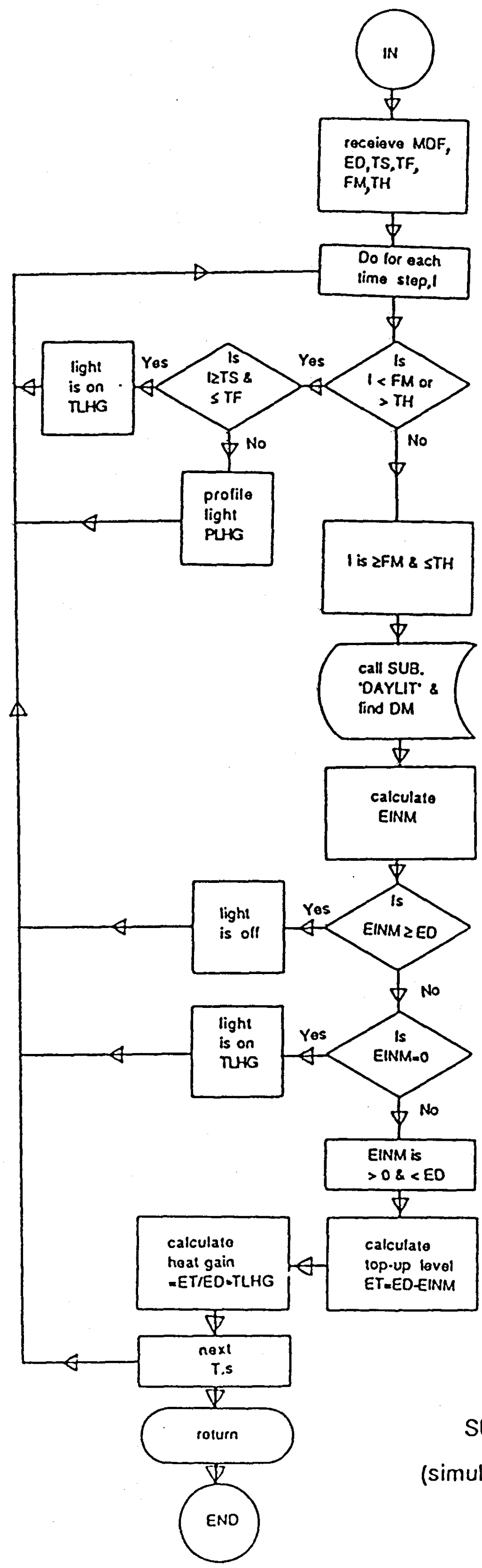
(b) If the value EINM is less than ED then it was assumed that the output level from the electrical lighting is only required to 'top up' to the design level, hence the heat emission from the difference (ED - EINM) was calculated only assuming a proportional relationship between the power input and the light output as indicated above.

(c) Finally if the value of EINM was zero then the lighting was fully on, and the heat emssion was calculated from the full lighting load. Flowchart 5.5 shows the logic of the simulation process.

5.5.3 Multi-Photoelectric Control (On-Off and Dimming)

The simulation given in the previous sections (5.5.1 and 5.5.2) apply to systems operated by a single control using the minimum daylight factor in the space to estimate the 'whole space' worst interior daylight. However, in a space in which the daylight factor varies considerably, more energy might be saved by controlling only those luminaires in areas of high daylight factor, rather than by relating the control of the whole system to the lowest daylight factor.

Alternatively, several controls might be used, one for each daylight factor zone. For example, the set of luminaires which is near windows could be controlled by an on/off photoelectric control, while the deep plan luminaires could be controlled by a dimming system. For such situations the simulation of the use of artificial lighting could be performed for each daylight factor zone. If the daylight factor zone is controlled by an on/off system then subroutine 'PONOFF' (Flowchart 5.4) could be called to simulate the lighting use and hence the heat emission accordingly, while if the daylight factor zone is controlled by a dimming system, then subroutine 'DIMM' (Flowchart 5.5) could be called to perform the simulation. This process could be performed for



FLOWCHRT 5.5

SUBROUTINE 'DIMM'

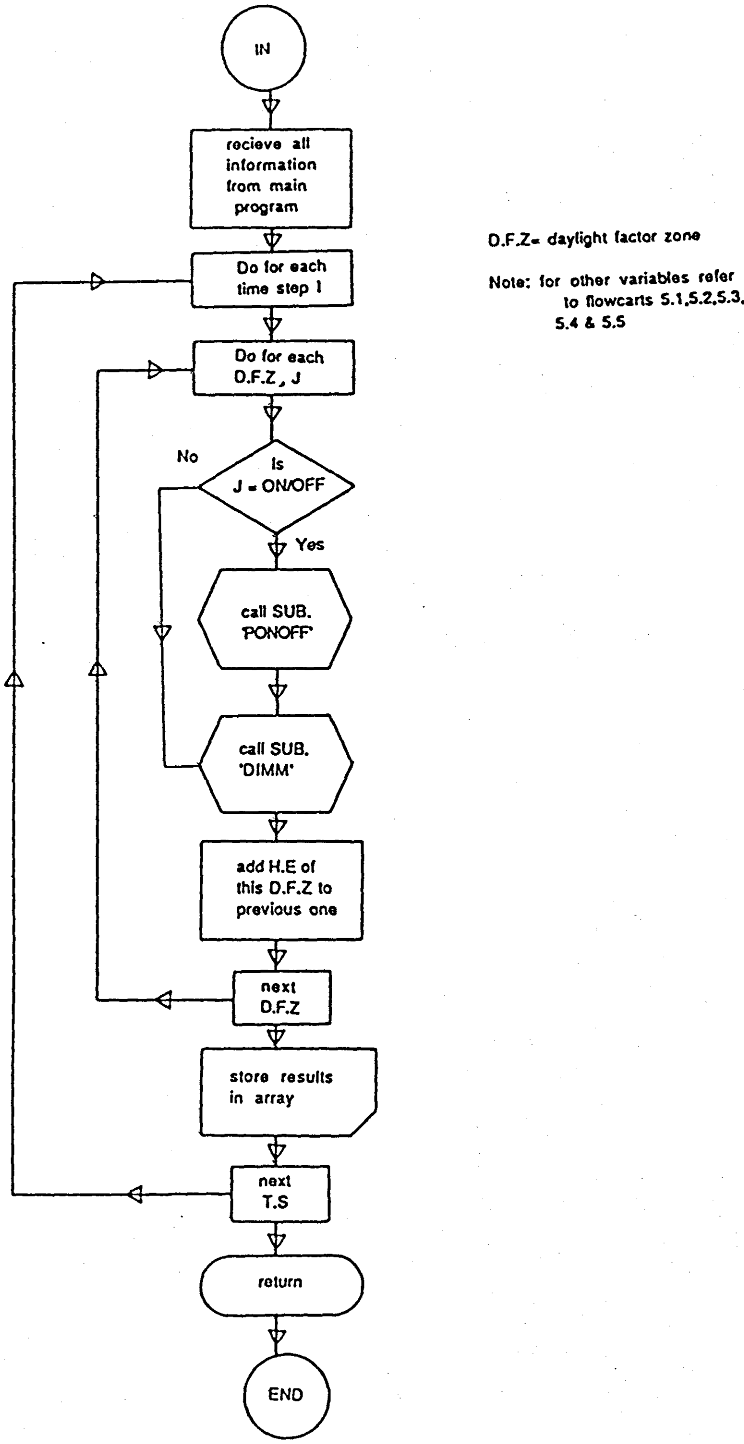
(simulation of lighting use controlled by photoelectric DIMMING) whatever number of daylight factor zones and at any time step the heat emission for the whole space could be added finally for all daylight factor zones. Flowchart 5.6 shows the logic of the simulation process.

5.6 LIGHTING USE AT THE WEEKEND

It was indicated in Section 4.5 that during the period of the weekend there was no data available about the movement of people in the office building hence occupancy patterns were not simulated and it was assumed to follow a simple profile. Since the simulations of artificial lighting use introduced in the previous sections were related to the occupancy patterns, and these patterns combined with all behavioural aspects were observed during the period of week days only, it became difficult, therefore, to simulate the lighting use during the weekend. Hence a simple profile was also assumed where the light was switched on when the occupation started and was switched off when it ended. The total lighting to be in use was input by the user of the program as a percentage of the total zone lighting (0-100%), and the heat emission was calculated during periods when the light was in use.

5.7 RESULTS AND DISCUSSION

In the previous sections of this chapter, the concepts of simulating the artifical lighting use according to the main types of control have been introduced. In this section, the profile representing the heat emission from lighting according to its use will be introduced and discussed for each type of control. Zone 1 of the IEA-O Building mentioned in Section 2.2. was chosen to perform the process of the simulation for 10 minute time steps. Table 5.3 shows the lighting characteristics of the zone and the data used in the simulation.



FLOWCHART 5.6

SUBROUTINE 'MIXED'
(simulation of lighting use controlled by mixed photoelectric (ON/OFF & DIMMING)

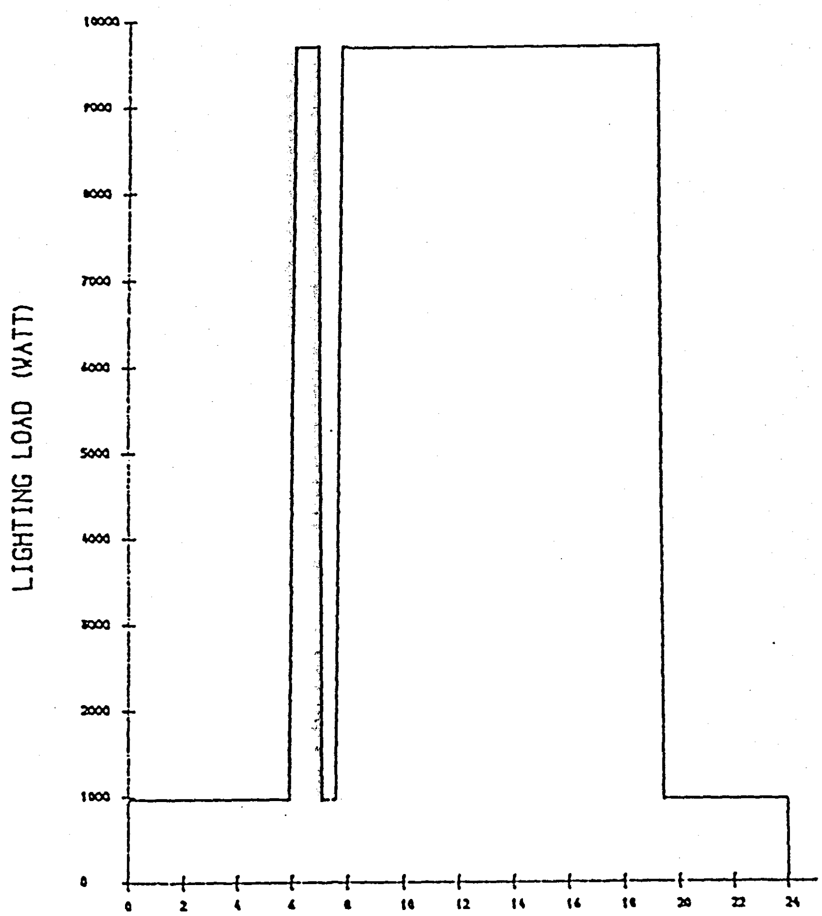
TABLE 5.3 The Lighting Specifications and the Lighting Data Used in the Simulation of the Lighting Use of Zone 1 the IEA-O the Building

Total lighting load	58087 watts
Convective/Radiative split	0.5/0.5
Design illuminance	450 lux
Minimum Daylight Factor	2%
The security lighting to be used out of occupation as a percentage of total load	10%
The period of cleaning activity	6.00-7.00 hrs

The profiles resulting from those simulations could be summarized as follows:

(1) Manual switching (on/off): It was mentioned that if the average probability of switching for 100 days of the winter season, for example, was 80% then it would be expected that the lighting would be switched on for 80 days. It was mentioned also that for any day if the lighting was switched on in the morning it would remain on until the space had become completely empty. This could be seen in Figure 5.3 which represents the heat emission profile from the lighting controlled by manual switching in a December day. The figure shows the security lighting which was used out of the occupation period (0-7.45 hrs and 19.25-24 hrs), and was assumed as 10% of the total lighting load. The cleaning activity was assumed to occur during the period 6.00 - 7.00 hrs, and for that reason the lighting was in full use during this activity. During the occupation period, which started at 7.45 hours and ended at 19.25 hours (as predicted by occupancy patterns model), the light was in full use also. If the lighting was not switched on in the morning, then the heat emission would have resulted only from the security lighting and the lighting used during the cleaning activity.

(2) Localised control: As an example, assume that the lighting was controlled by localised switching and constitutes 90% of the total zone lighting and the general background is 10%. From Figure 5.4 it can be seen



TIME (0-24) HRS

FIG .5.3

LIGHT. HEAT GAIN PROFILE (MANUAL CONTROL), FOR A WINTER DAY therefore that because the lighting control was made localized and their use was related to the individuals, the use of the lighting was generally less than the case of the manual control and hence the heat emitted was also less. It shows also that the lighting use after lunch period was much less than it was in the morning because the daylight had improved significantly, and the probability of switching at the arrival time after lunch was small. The profile presented in Figure 5.4 represented the lighting use on a December day (where the daylight availability was the minimum compared with other months. See Table 5.1). However, if the lighting use was simulated for a summer day, say, in June, then the lighting and the heat emission profile would be much less. See Fig 5.5.

(3) Photoelectric on/off: If the zone was controlled by an on/off photoelectric control, then the system compares the minimum working plan illuminance with the design level. If it was equal to or greater than the design level, then the lighting would be switched off, otherwise it would be on. Figure 5.6 shows the lighting use for a December day where at any time, the minimum working plan illuminance had never reached the design illuminance. For that reason the lighting was on all day. In summer (say, June) Figure 5.7 shows that the lighting was on only at the beginning and at the end of the working day because the minimum working plan illuminance was less than the design level, while for most of the working day, the lighting was off.

(4) Photoelectric dimming: Figure 5.8 shows that the lighting use controlled by a dimming system for the same winter day (December) is less than the on/off switch (Figure 5.6 because all the time, the dimming system had ensured that the sum of the minimum dayalight available in the space and electric lighting reached the design level (450 lux). The case could be seen also in summer, where Figure 5.9 shows that even in early morning or late evening periods the lighting use never reached the

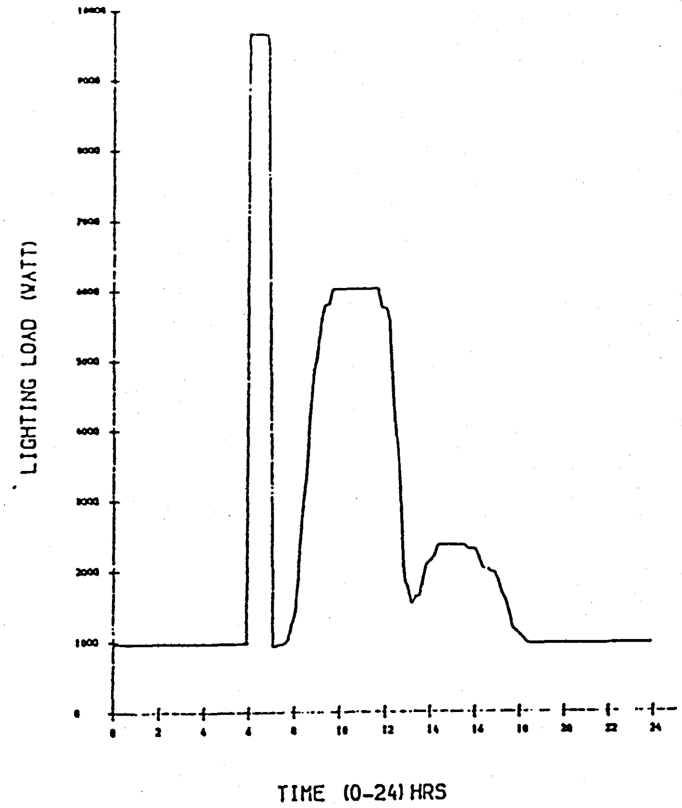


FIG .5.4

LIGHT. HEAT GAIN PROFILE (LOCALISED CONTROL, PULL CORED OR TABLE LAMP) ,FOR A WINTER DAY

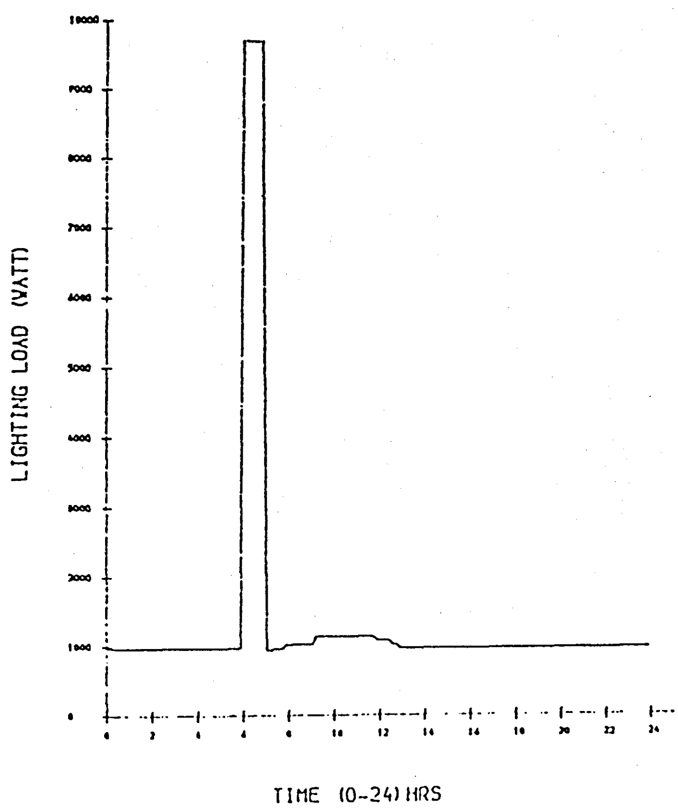


FIG .5.5

LIGHT. HEAT GAIN PROFILE (LOCALISED CONTROL ,PULL CORED OR TABLE LAMP) ,FOR A SUMMER DAY

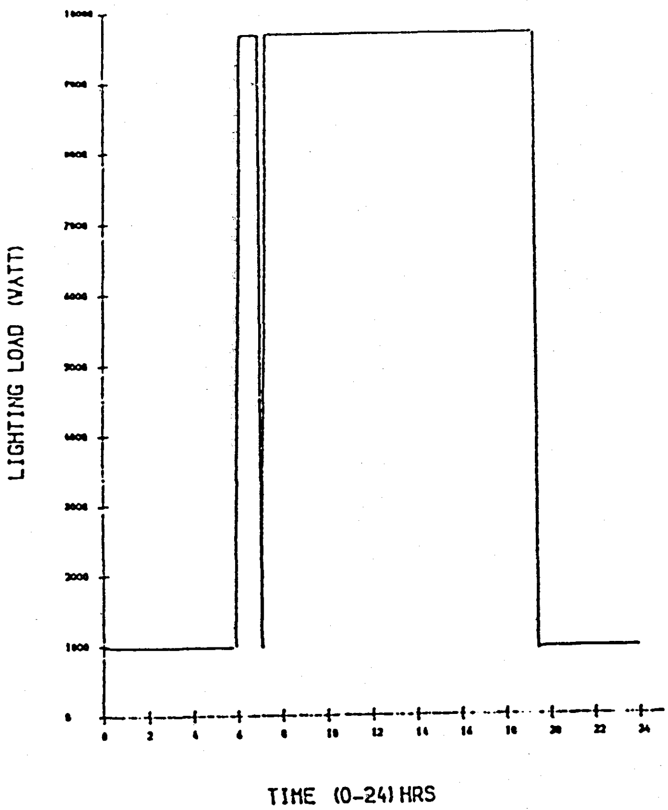


FIG .5.6

LIGHT. HEAT GAIN PROFILE (PHOTOELECTRIC CONT ., ON-OFF) , FOR A WINTER DAY

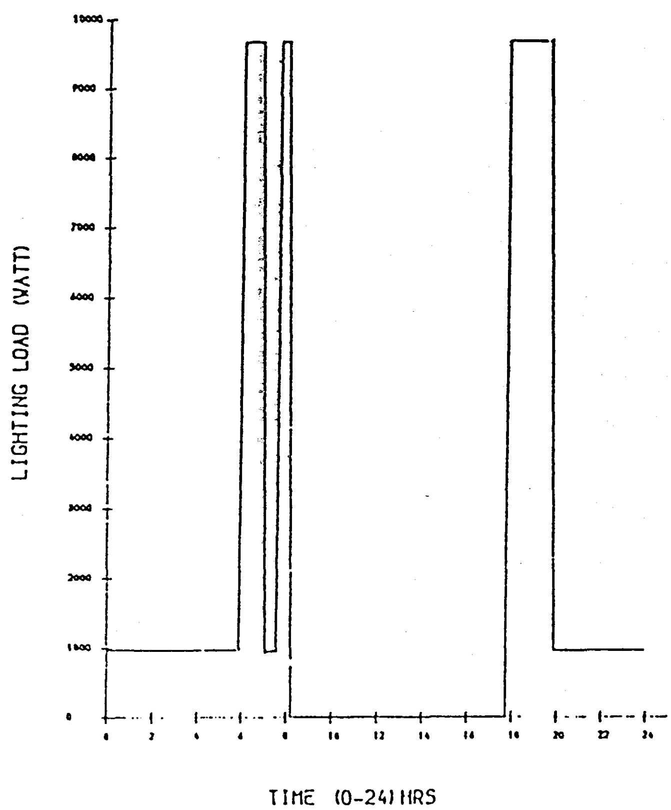


FIG .5.7

LIGHT. HEAT GAIN PROFILE (PHOTOELECTRIC CONT ., ON-OFF) , FOR A SUMMER DAY

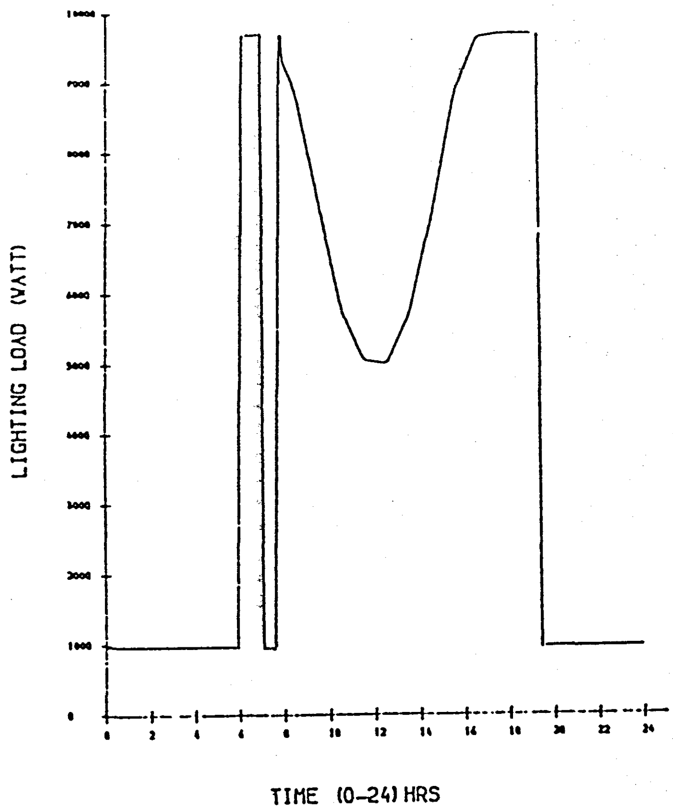


FIG .5.8

LIGHT. HEAT GAIN PROFILE(PHOTOELECTRIC CONT .,DIMMING),FOR A WINTER DAY

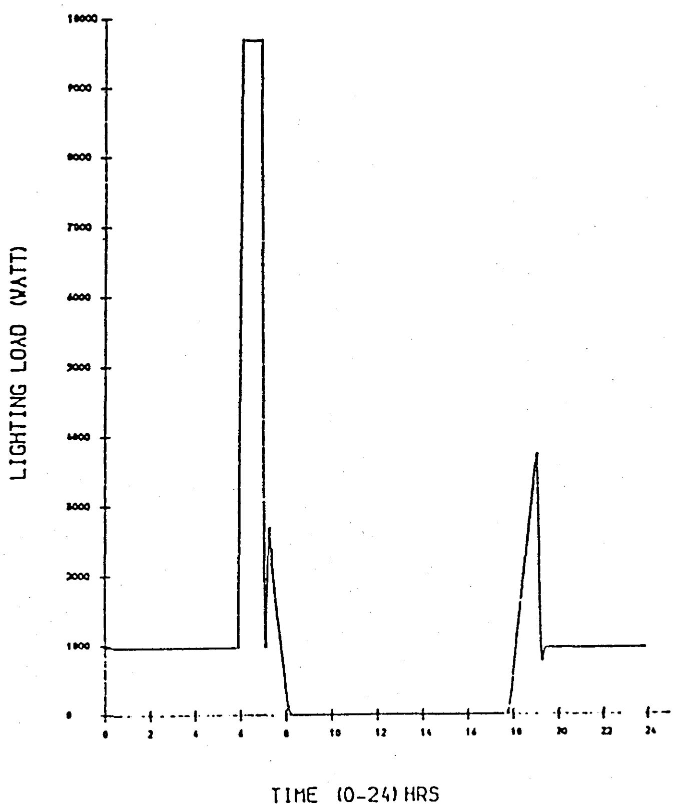
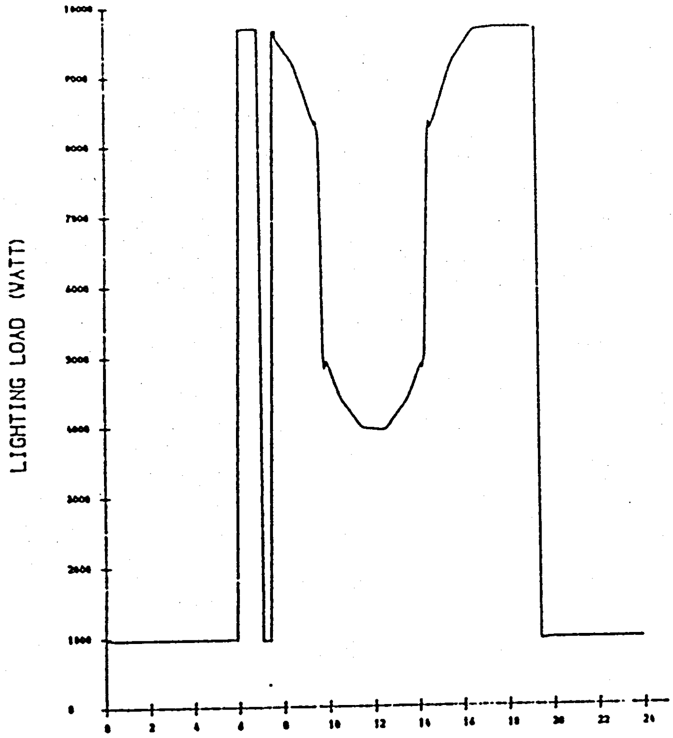


FIG .5.9

LIGHT. HEAT GAIN PROFILE(PHOTOELECTRIC CONT DIMMING),FOR A SUMMER DAY maximum value and the difference can be seen clearly when it is compared with Figure 5.7 (on/off controls) for the same summer day (June).

(5) Mixed (on/off and dimming): Supposing that the same mentioned space assumed to have two daylight factor zones, the first daylight factor zone was controlled by an on/off photoelectric switch and was controlling the set of luminaries near the windows where the daylight factor is high (assumed as 8%), and the lighting serving this daylight factor zone constititued 30% of the total lighting load of the space. The second daylight factor zone was controlled by a dimming system and represented the core area of the total space where the daylight factor was assumed as 2% and the lighting load was 70% of the total load. The lighting use and the heat emission profile therefore could be seen in Figure 5.10 for the winter day (December) where the lighting use is less than the case of a dimming system only (see Figure 5.8) because the lighting use in the on/off daylight factor zone was very small since the value of the daylight factor was high. However, in summer Figure 5.11 shows that the lighting use is not different from that in Figure 5.9 (for the dimming) because the daylight available in the zone in both cases was higher than the design illuminance for most of the working day.

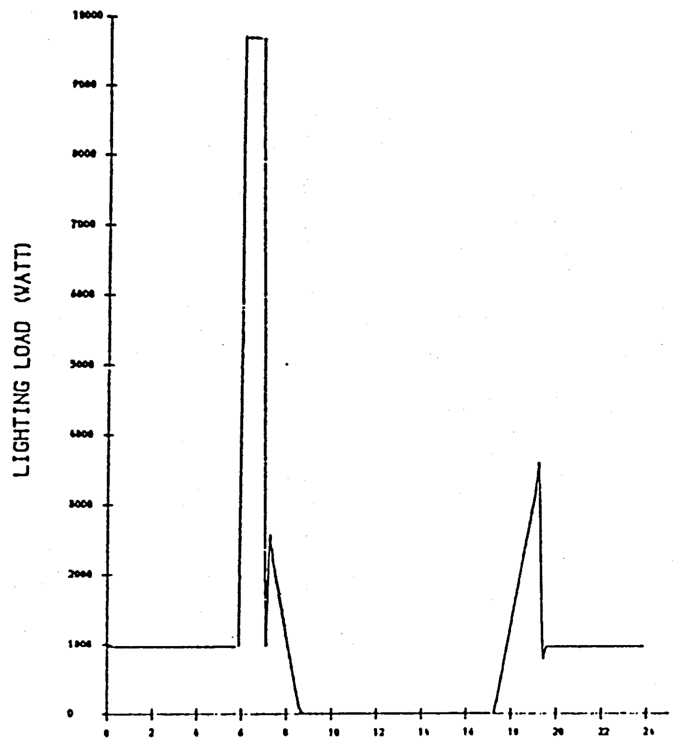
Generally speaking, the models presented for simulating the lighting use controlled by traditional manual or localised switches were developed from the BRE research. The stochastic profiles of lighting heat emission were less than the simple constant profiles. However, a question might arise about a certain aspect of switching activity not included in the model. This aspect is the 'during the day' switching. For example, if the lighting was off at the beginning of the day, there are some occasions when the artificial lighting will be switched on during the day due to reasons as (a) when the daylight falls significantly especially in winter and after the lunch period, and (b) when it becomes cloudy during the working hours. The BRE field studies [5.3.3]



TIME (0-24) HRS

FIG .5.10

LIGHT. HEAT GAIN PROFILE (MIXED PHOTOELECTRIC CONTROL (ON-OFF & DIMMING), FOR A WINTER DAY



TIME (0-24) HRS

FIG .5.11

LIGHT. HEAT GAIN PROFILE (MIXED PHOTOELECTRIC CONTROL (ON-OFF & DIMMING), FOR A SUMMER DAY conducted in multi-person offices tend not to support the idea of 'during the day' switching. They also indicate that the frequency with which the daylight level fell substantially below its level at the start of occupation seems to have been very small. Some factors which might be involved [5.3.2] in not switching during the day are: (a) reluctance of occupants to take action which might disturb or distract others in the space, (b) a disinclination to interrupt work in order to move to light switch and (c) the good adaptation of the eye to gradually decreasing light levels. All of these factors would tend to create a different, less sensitive switching curve than that for the start of a period of occupation. It seems more likely that the observed scarcity of during the day switching in the multi-purpose offices is primarily due to the fact that if lights were 'needed', it is very likely that they were already on as a result of the action taken at the beginning of the day.

On the other hand, the modelling of the 'during the day' switching and establishing the probability of switching is not a straightforward process. For this to be done, more field studies are necessary. The sort of data that is required would have to be obtained from monitoring a multi-person office over a sufficient period of time (normally over year). The 'during the day' probability of switching would of course be related to the daylight taking into consideration the cloudy periods. When the 'during the day' probability of switching is used to predict the use of lighting, it should be noticed that the daylight would have to be predicted first taking into consideration the cloud situation. This also requires realistic data (for a long period of time) to establish a realistic cloud prediction model. The studies required to achieve this would require a long period of research. Sufficient time to develop these refinements was not available in the present study but it is doubtful if the potential advantages would justify the cost of such extensive studies.

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6. *STOCHASTIC SIMULATION OF EQUIPMENT USE AND THE RESULTANT HEAT EMISSION*

6.1 INTRODUCTION

It was mentioned in Section 1.1.1 that the use of office equipment has not been covered as widely as lighting and the main reasons were given. Moreover, if effort is required to gather information about the use of equipment according to its type (personal or general) and according to its mode (running or stand-by) over a period of time, this effort might be accompanied by some difficulties. For example, (1) the security problems, (2) people generally do not like to be watched during their work, (3) people may change their behaviour when they are being watched, hence unrealistic observations may be obtained, (4) this effort may finally become costly and time consuming. Because of these difficulties, an approach was suggested to model the use of equipment according to the following factors:

(1) occupancy patterns

(2) type and function of equipment (for personal or general use)

(3) the daily average probability of use

The average probability of use was regarded as the average use of a piece of equipment expressed as a percentage of an occupation period (eg. the average use of photocopier is 30% of the occupation period). This value is to be input by the user of the model according to the unit type and function while the model simulates the use of the unit according to this value and the building occupancy patterns. This assumes that the use is random throughout an occupation period. It is important to emphasize that more accurate the input value, the more realistic is the prediction of the unit use. Therefore, for each type of equipment (personal or general) a subroutine of a computer program has been written to simulate their use. Three cases will be introduced for modelling the use of equipment for any zone: the first case when the zone is equipped with personal use type only, the second when the zone is equipped with general use type only and the third case when the zone is equipped with both types. These cases will be discussed in detail in the following sections.

6.2 ZONE WITH PERSONAL TYPE EQUIPMENT

It was mentioned in the previous section that the use of a certain type of equipment was related to the occupants and the average probability of use. The occupancy pattern model provided the required information about the status of the zone occupancy and identifies the time of arrival and departure of each person. By definition, the use of each piece of equipment of personal type was related to one person. Since it is not known which person of the zone is associated with the a particular piece of equipment, the selection of the person was assummed to be random. Hence for each peice of equipment a random person was selected from the zone occupancy and assummed to be using the unit during the working time. To ensure that each person was associated with only one unit, the selection of the persons was taken sequentially from the array of arrival/departure times which was defined randomly from the occupancy patterns model. It is worth mentioning that the efficiency of work of the human being on whatever type of personal equipment usually varies between the morning and the afternoon duration (ie the average number of hours worked before lunch is probably higher than the average number of hours worked after lunch). Hence, for accuracy, it became important to define two average probabilities of use one for the morning duration, and the other for the afternoon duration for each type of personal equipment. For each duration, the average probability of use is to be input by the user of the model according to the type and function of the unit. To simulate the use of any piece of personal equipment, the mode of use of the unit (running or stand-by) was simulated at each time step according to the probability of use, where a random cumulative number was generated between the values zero and one as explained before. If the generated number was equal to or less than the average probability of use then the unit was assumed to be in the running mode and the heat gain at this time step is calculated, otherwise the unit was assumed to be in the stand-by mode. The use of the random number in each time step according to the average probability of use will provide the realistic variation of the unit use throughout an occupation period.

The values of sensible heat emission for each mode and the convective/radiative splits are given by the designer. For example, if the simulation time step was 5 minutes and the average probability of use in the morning duration was 80%, then it would be expected that the unit would be in use for approximately 80% of the morning duration and the use would occur in time steps distributed randomly over the occupation period.

If the number of types of personal equipment is known, (e.g. one type represents VDU's and another type represents typewriters etc) and the number of units of each type is known also, then the simulation of the use of each unit of a type could be summarized as follows for each time step:

(1) The use of each personal unit was assumed to be associated with one individual of the staff. The pattern of the individual is taken from the array of arrival/departure times which was simulated randomly by the occupancy pattern model.

(2) If the simulated time step was out of the occupation period of the mentioned individual, then the asociated unit was assumed to be off and the heat emission was zero. The value of the heat emission at this time step was stored in a 3 dimensional array, one dimension representing the unit numbers, the second representing the time step and the third the value of the heat emission. The same concept was introduced in Table 4.7.

(3) If the time step was within the morning duration of the individual then a random number was generated and was compared with the average probability of use for the morning duration. If the random number was less than or equal to the probability of use then the unit was assumed to be in the running mode, while if it was greater, then the unit was

assumed to be in the stand-by mode. The heat emission was calculated accordingly and stored in the same arrray at this time step.

(4) If the time step was within the lunch duration of the person, then the unit was assumed to be off and the heat emission from the unit was zero. This value was stored in the array at the time step.

(5) If the time step was within the afternoon duration then a random number was generated also and compared with the average probability of use for the afternoon duration as explained in 3 above. The heat emission was calculated and stored in the array at this time step.

(6) The process was repeated for each time step of the day (0 - 24 hours).

(7) The steps 1 through 6 above were repeated for each unit of the same type and for each type of personal unit.

(8) The total heat emission at each time step was added for the units of all types to find the total heat emission from the zone equipment.

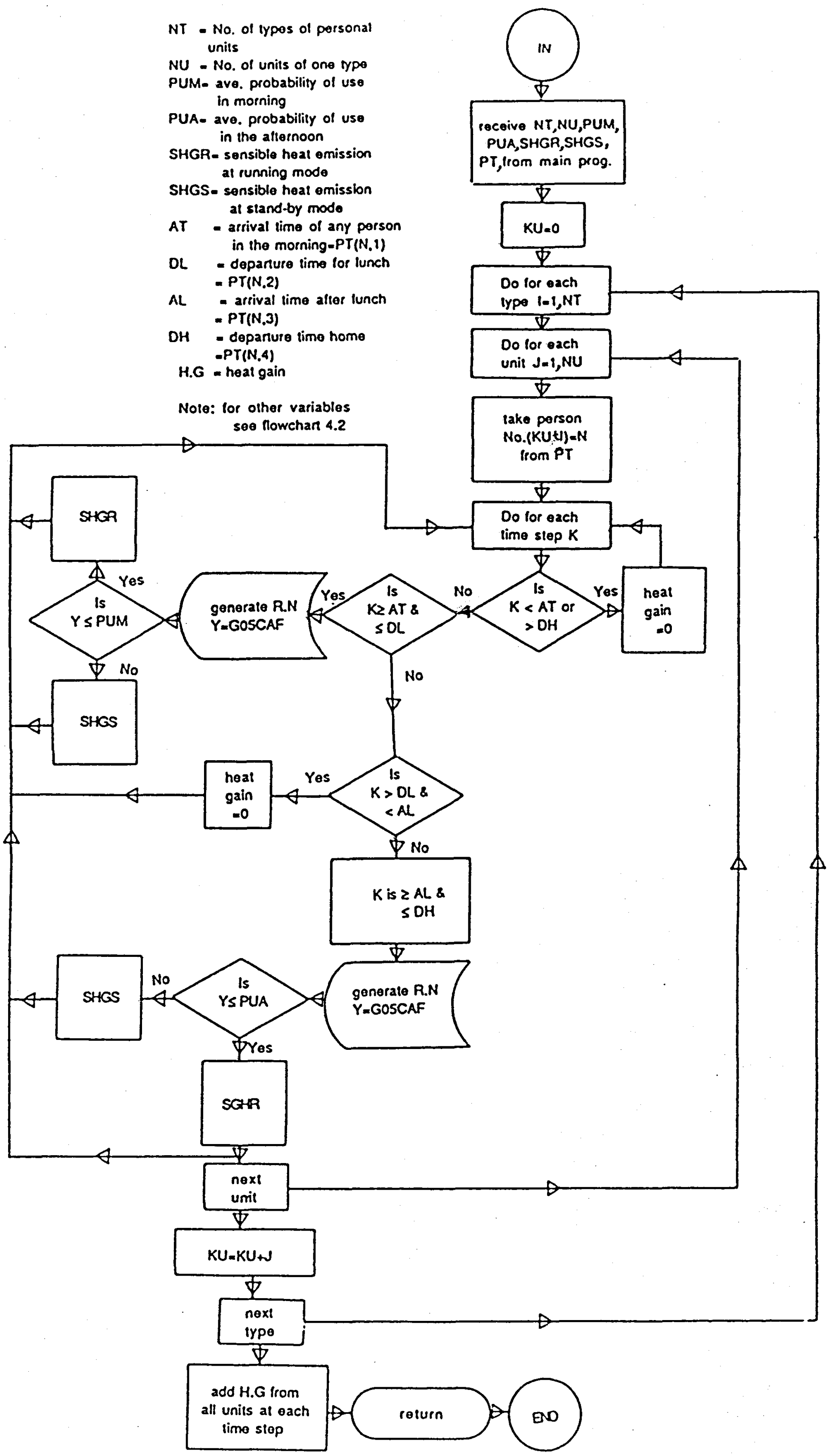
The logic of the simulation process is shown in Flowchart 6.1 which represents a subroutine of the computer program.

6.3 ZONE WITH GENERAL TYPE EQUIPMENT:

Unlike the personal use equipment, the use of the general equipment is not associated with a particular person in the zone, but it could be used by any person. In fact, the use of general equipment is a random process which varies from one day to another and is used only when they are needed. An example is the photocopier, a computer terminal or a printer, etc. Each of these units might be used by any individual in the zone during the working hours. Since these units are for general use, the daily average number of hours they are used or, in other words, the average probability of use, has to be known for each type (ie the <u>daily</u> average probability of use). These are to be input by the user of the model. For the simulation of the general use equipment, it was assumed that their use would be within the occupation period only. At any time step within the lunch period, if the space became empty

NT = No. of types of personal units
NU = No. of units of one type
PUM = ave. probability of use in morning
PUA = ave. probability of use in the afternoon
SHGR = sensible heat emission at running mode
SHGS = sensible heat emission at stand-by mode
AT = arrival time of any person in the morning = PT(N,1)
DL = departure time for lunch = PT(N,2)
AL = arrival time after lunch = PT(N,3)
DH = departure time home = PT(N,4)
H.G = heat gain

Note: for other variables see flowchart 4.2



FLOWCHART 6.1
SUBROUTINE 'PEREQP'
(simulation of equipment use of personal type)

(this occurs rarely in the case of the flexi-time office and for zones of very low occupancy) then the unit was assumed to be at the stand-by mode.

Suppose that the daily average probability of use of a photocopier was 30%, then it would be expected that the unit would be in use for approximately 30% of the time of the occupation period and occuring in time steps distributed randomly over the occupation period. The use of the random number will provide the realistic variation of use.

If the number of types of the general units is known, and the number of units of the same type is also known, then the simulation of each unit of a type could be summarized in the following proceedures for each time step:

(1) If the time step was out of the occupation period, then the unit was assumed to be off, and the heat emission was zero. The value was stored in the same 3 dimensional array.

(2) If the time step was within the occupation period, then a random number was generated and was compared with the average probability of use. If the random number was less than or equal to the probability of use, then the unit was assumed to be in the running mode. Otherwise it was in the stand-by mode. The heat emission was calculated accordingly and stored in the array.

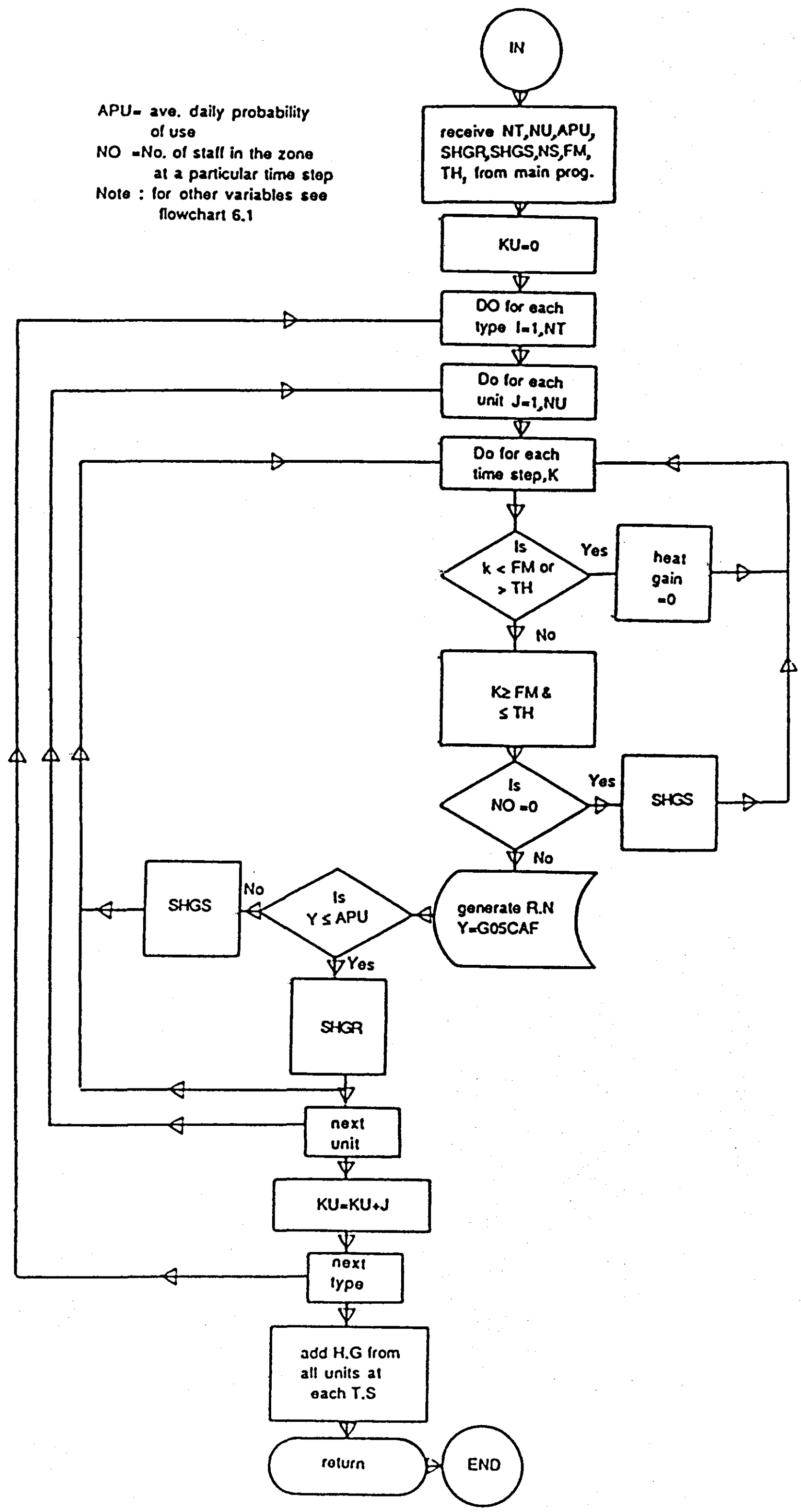
(3) If the time step was within the lunch period and the space was empty during this time step, then the unit was assumed to be in stand-by mode, where the heat emission was calculated and stored in the array.

(4) The process was repeated for each time step of the day (0 - 24 hrs).

(5) The steps 1 through 4 above were repeated for each unit of a type and for each type of the general equipment.

(6) The heat emission from the units of all types was added at each time step to find the total zone equipment heat emission. The logic of the simulation process is shown in Flowchart 6.2 which represents a subroutine of the computer program.

APU= ave. daily probability of use
NO =No. of staff in the zone at a particular time step
Note : for other variables see flowchart 6.1



FLOWCHART 6.2
SUBROUTINE 'GENEQP'
(simulation of equipment use of general type)

6.4 ZONE WITH MIXED EQUIPMENT (PERSONAL TYPE & GENERAL TYPE)

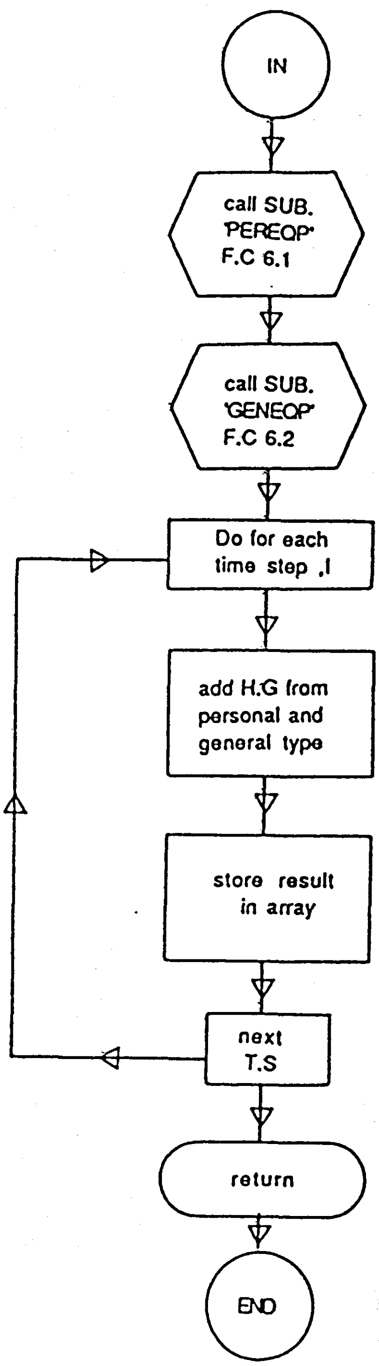
Since the simulation of equipment use was introduced for each type, personal or general, it became easy to simulate the use of equipment in a zone containing both types. The use of the equipment of the personal type was simulated first by calling the subroutine 'PEREQP', Flowchart 6.1 and the heat emission values at each time step (0 - 24 hrs) was calculated for all the personal units and stored in an array of heat emission. Then the use of general equipment was simulated at each time step by calling subroutine 'GENEQP', Flowchart 6.2 and the heat emission values of each time step (0 - 24 hrs) was also calculated and stored in another array of heat emission. The total zone equipment heat emission was therefore calculated by adding the values of the heat emission of the personal type equipment to the heat emission values of the general equipment at each time step of the day (0 - 24 hrs). The process is shown in Flowchart 6.3.

6.5 EQUIPMENT USE AT THE WEEKEND

For the same reasons mentioned in section 4.5 and 5.6, when the space was occupied during Saturday or Sunday, it was assumed that the use of equipment followed a constant profile. If the space was equipped by either personal or general type equipment, then the percentage equipment that would be in use for each type was decided by the designer. This was done by using the information already available for equipment at weekdays. The heat gain from the equipment which was in use was calculated by assuming that these units were in full running mode during the occupation period (ie total load from the units to be in use). If the zone was equipped with both types (personal and general) of equipment, then the same assumption applied on each type, and the total heat emission was calculated from all equipment to be in use.

6.6 RESULTS AND DISCUSSION

The use of office and electronic equipment was related to the zone occupancy,



Note : refer to flowchart 6.1 & 6.2 for all variables

FLOWCHART 6.3

SUBROUTINE 'MIXEQP'

(simulation of equipment use in a zone containing personal and general type)

type of equipment and the average probability of use. The simulation of each type was explained and the flowcharting of the computer subroutines was also introduced. To investigate the results of the simulation of each introduced case, the stochastic heat emission profiles resulting from the use of equipment will be introduced and discussed. Again zone 1 of the IEA-O Building was selected to perform the process of simulation in 10 minute time steps. Table 6.1 shows the zone equipment characteristics, and from this table the following three cases have been considered:

(1) When the zone was equipped with personal type only (1 and 2 of Table 6.1):

Since the use of each piece of equipment was related to one person, and was assumed to be in use during his presence in the zone, then it would be expected that the personal equipment patterns follow from the zone occupancy patterns. Figure 6.1 shows that the use of the zone personal equipment increases during the arrival period in the morning and was a constant maximum value when the total number of staff existed in the zone. (The maximum value was constant between approximately 10 hrs and 11.80 hrs because the heat emission value from each unit at running mode was equal to the heat emission value at stand-by mode. (See 1 and 2 of Table 6.1) Because it was considered that each individual associated with a personal unit had switched his unit off at the departure time for lunch, the heat emission profile went down to the minimum value which is at approximately 13 hours. (This value was not zero because of the overlap which occurred during this period). The profile went up again when the staff arrived after lunch as they started switching on their personal equipment again. Finally, when the staff started departing home the heat emission profile went down to zero. This value (zero) was reached when the space became completely empty.

(2) When the zone was equipped with general type only (3 through 6 of Table 6.1):

TABLE 6.1

The Characteristics of Equipment of Zone 1 of the IEA-O Building

No.	Source Description	Type	Performance /Status	Heat Emission (W)	Average Probability of Use	No. of Units	Conv./Rad. Split
1	VDU	Personal	Running Stand-by	200 200	morning = 80% afternoon=70%	40	0.2/0.8
2	Typewriter	Personal	Running Stand-by	100 100	morning = 85% afternoon=70%	60	0.2/0.8
3	Printer	General	Running Standby	1000 1000	25% per day	5	0.4/0.6
4	Photocopier (Small)	General	Running Stand-by	1500 750	35% per day	4	0.8/0.2
5	Photocopier (Large)	General	Running Stand-by	3500 1500	35% per day	4	0.8/0.2
6	Coffee Machine (Large)	General	Running Stand-by	3000 500	10% per day	4	0.8/0.2

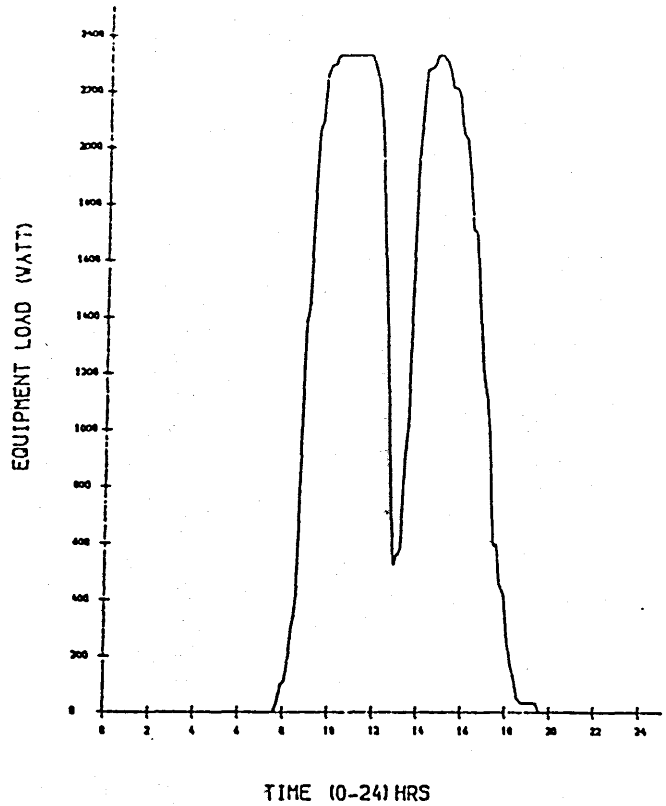


FIG . 6. 1

EQUIPMENT HEAT GAIN PROFILE (PERSONAL TYPE)

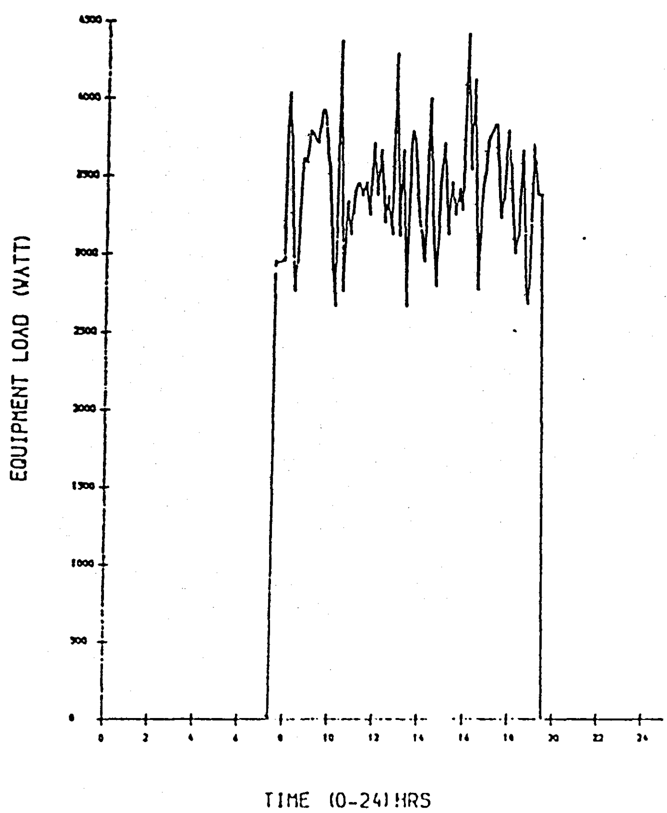


FIG . 6. 2

EQUIPMENT HEAT GAIN PROFILE (GENERAL TYPE)

Since the use of general equipment was to be a random process, then it would be expected that the heat emission profiles varied randomly during the working hours according to the use. Table 6.1 shows that the values of the heat emission at the stand-by mode were less than the values at the running mode. Therefore at any time step within the working hours, it would be expected that some of the units would be in the running mode, and the rest were in the stand-by mode. This case would change from one time step to another, hence the resulting profile could be as shown in Figure 6.2.

A question might arise about the shape of this profile which doesn't follow the occupancy profile (ie. the profile of the number of people in the zone). This could be explained as follows:

(a) The simulation of general equipment was based on the daily average probability of use (as a percentage of occupation time). If the average probability of use was related to the actual number of people in the zone at each time step (ie. by multipying it by the proportion of people in the zone), then the resultant profile of equipment use would follow the people profile. However, that would lead to an incorrect predicted average probability of use (ie. the predicted value will be less than the actual input value of the average probability of use). For that reason, the average probability of use was not multiplied by the proportion of people existing in the zone. This should have a minor effect on the prediction at the beginning and the end of the occupancy period only.

(b) Because it was assumed that none of the units were switched off during the lunch period (ie. assumed in the stand-by mode), the profile doesn't show the same behaviour as for the personal equipment during this period.

If a more accurate simulation was required then one possible technique would be to observe how the probability of use varied with time of day.

This could be used directly to simulate usage patterns but the data collection would be laborious since it needs to be achieved for each type of equipment. This is unlikely to be worthwhile because the difference in heat gains would be small unless the variations were large.

(3) When the zone was equipped with both types (Table 6.1):

From the previous 2 cases it could be concluded that if the space was equipped with both types, then at any time step the use of equipment would be a mixture of presonal and general types, and the profile go up and down according to the mode of use. See Figure 6.3. However, because the pattern of use of personal equipment followed the staff patterns, the figure shows that the maximum use of total zone equipment was when the total staff were present in the zone (see the profile at approximately 11.00 and 15.00 hrs). For the same reason, the use during lunch period decreased and increased according to the staff patterns at this period.

Generally speaking, these figures indicate that the stochastic heat emission profile of equipment is less than the simple constant profiles.

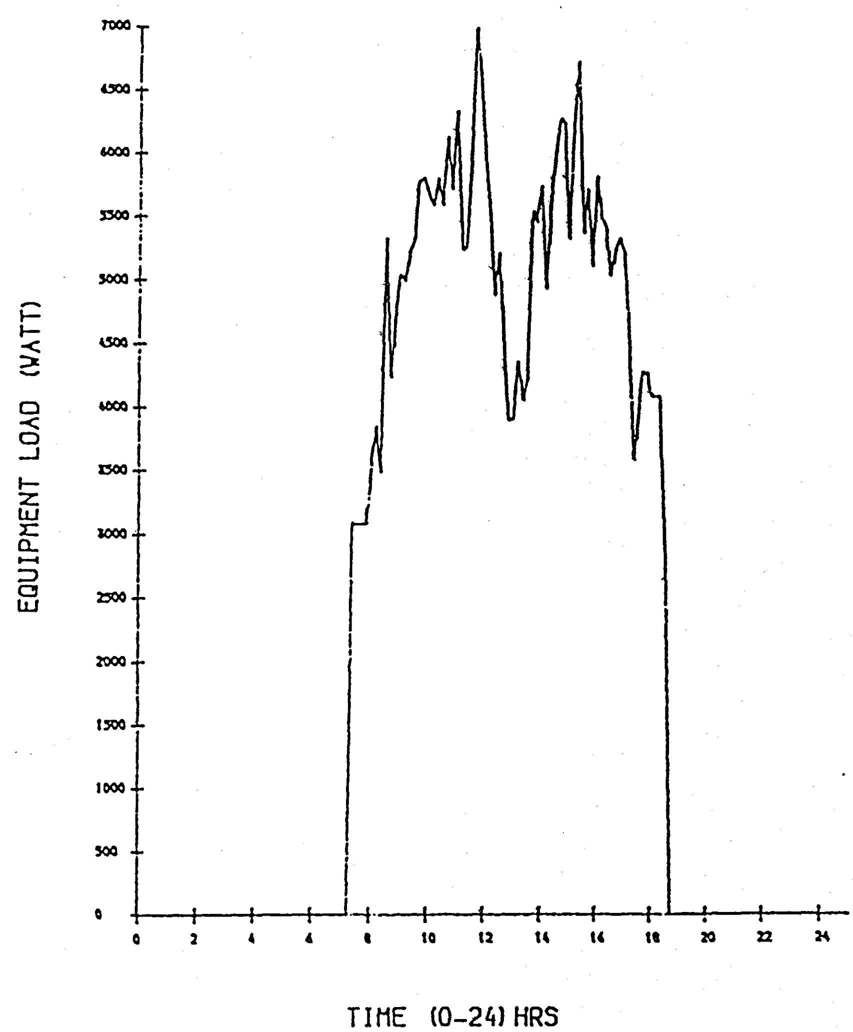


FIG .6.3

EQUIPMENT HEAT GAIN PROFILE (PERSONAL AND GENERAL USE TYPE

7. *ANALYSIS OF BUILDING ENERGY REQUIREMENT USING ESP*

7.1 INTRODUCTION

In the previous three chapters 4, 5 and 6, the concepts of predicting the building internal heat gains have been introduced and the expected profile of the heat emission from each source (people, lighting and equipment) has been presented. It is suggested that these stochastic profiles were developed to provide a better estimation of building internal heat gains. Hence a better estimation would be expected for the heating/cooling loads and the building energy requirements. The computer program which has been written to achieve the simulation processes was provided with enough flexibility to allow changes in the input data to investigate different design situations, (eg. effect of the number of visitors, daylight factor, type of light control, type and number of equipment used, etc).

As mentioned earlier, the building energy requirements were analyzed on ESP, and for that reason the output of the stochastic model was arranged to fulfill the requirements of ESP. For each time step the total sensible convective, sensible radiant and latent internal heat gains (all in Watts) were supplied for each zone of the building. The output of each zone was presented to ESP for each simulated day. It is important to mention that to identify the simulation period, the date and the day of the week, the following three subroutines have been taken from ESP:

(a) Subroutine "DAY": "DAY" computes the year day number from the day and month number (which is given by the user) to calculate the total number of simulated days.

Year day no. 1 = 1st January

Year day no. 365 = 31st of December

No leap year is considered.

(b) Subroutine "DAYR": "DAYR" computes the current simulated day and month numbers (that is, the date) from the year day number, where

Year day no. 1 = 1st January

Year day no. 365 = 31st of December

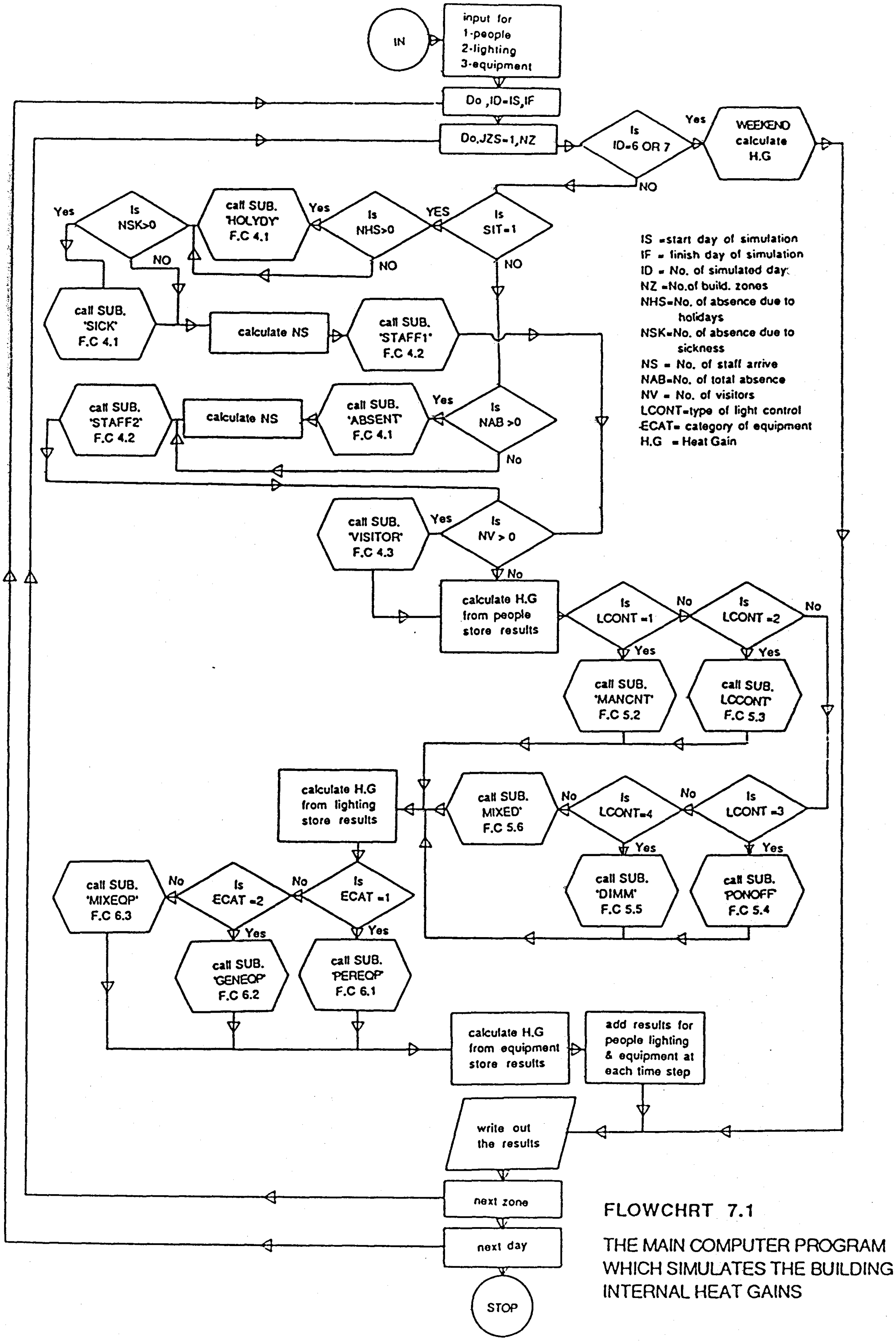
No leap year is considered.

The ouput of this subroutine was required to up-date the results and also required as an input to the following subroutine.

(c) Subroutine "WEEKDAY": "WEEKDAY" computes the day of the week given the date, ie. an input of day, month and year will return: Mon. = 1, Tues. = 2, Wed. = 3, Thurs. = 4, Fri. = 5, Sat. = 6 and Sun. = 7. These are required to identify Saturday and Sunday from the other weekdays.

The logic of the main simulation program which invites the different subroutines to perform the simulations of the zone internal heat gains is shown in Flowchart 7.1. The predictions of building heating/cooling loads and the total energy requirement have been performed on ESP using the stochastic profiles of the internal heat gains. To investigate the significance using the stochastic profiles, the results of predictions were compared with two constant profiles. The first one assumed that heat emission from people, lighting and equipment were constant maximum values starting at 9.00 hrs and ending at 17.00 hrs.

The second was the same as the first profile but started at 7.00 hrs and ended at 19.00 hrs. Energy predictions and results comparisons will be presented in the following sections.



FLOWCHRT 7.1

THE MAIN COMPUTER PROGRAM WHICH SIMULATES THE BUILDING INTERNAL HEAT GAINS

7.2 PREDICTION OF BUILDING ENERGY REQUIREMENTS

The prediction of building energy requirements has been carried out on the IEA-O building mentioned in Section 2.2 by using ESP. The same control strategy was also adopted where 2 hours of preheating/cooling was assumed and the zones were considered to be controlled at 23° C in winter and 24° C in summer when the building was occupied.

Four simulation periods were selected for this analysis: the winter week (11-15 December), the spring week (13-17 March), the summer week (19-23 June) and the autumn week (9-13 October). The typical U.K. climate data (Kew 1967, south of England) which is available within ESP was used in the analysis. The stochastic internal heat gain profiles for the typical zones of the IEA-O building were presented to ESP as total sensible convective, sensible radiant and latent heat gains. These were predicted depending on the information provided in Table 2.1 for the people and lighting, and Table 6.1 for the equipment.

To investigate the effect of the minimum daylight factor on the building energy requirements, two values have been investigated: one value was 2%, and the other value was 0.5%. For each daylight factor value different types of lighting control have been analyzed to investigate the differences in building energy requirements caused by the type of lighting control, and to compare them with the simple constant profiles mentioned earlier. These types of lighting control are the traditional manual, the localised and the photoelectrical controls. The first two types of control were investigated for each simulated week, while the third was only for the winter and summer weeks. To investigate the effect of using different time steps in the stochastic model, the predictions of building energy requirements have been carried out for 5, 10, 20, 30, 60 minute time steps. This was carried out when the zones were controlled by manual lighting control and for the winter and summer weeks only. To ensure that the comparisons were valid, the building energy requirements were predicted for the constant profiles (9-17 hrs) for the same mentioned time steps. The type of lighting control was not considered by the simple constant profiles because the maximum lighting load was assumed as a constant value during the occupation period.

The prediction of the building heating/cooling loads have been started with stochastic profiles, where the building control strategy assumed that the preheating was between 5.00 hrs and 7.00 hrs, and the normal heating/cooling was between 7.00 to 19.00 hrs. This control strategy was adopted because the stochastic internal heat gain profiles were expected to be generally between 7.00 hrs and 19.00 hrs with little difference from one day to another. The following procedures summarize the cases considered for the predictions of building heating/cooling loads and energy requirements when the stochastic internal heat gain profiles were used.

(1) When the minimum daylight factor in each zone was assumed as 2% (a high value), the following loads and energy predictions were carried out and the results are listed in Table 7.1

(a) When each zone of the building was assumed to be controlled by manual on/off light controls. For the winter and summer weeks, the predictions were carried out for 5, 10, 20, 30 and 60 minute time steps while for the spring and autumn weeks they were carried out for hourly time steps. The stochastic internal heat gain profile of this case is shown in Figure 7.1 for the 5 minute time step and for the winter week. This profile represents the total predicted sensible convective and total sensible radiant heat gain of zone 1 in the IEA-O building. For the bigger time steps the profiles were accumulated from the 5 minute time-steps and submitted to ESP. It is worth mentioning that during the accumulation process it is not expected that the building total internal heat gain increased linearly because the values of the zone internal heat gain varied from one time step to another as they were stochastic. Figure 7.2 shows the accumulated profile of zone

TABLE 7.1

Loads and Energy Predictions Using the Stochastic Profiles of Internal Heat Gain. The Daylight Factor of the Zones is 2% and the Building Control Strategy is 5.00 to 7.00 Preheating, 7.00 to 19.00 hrs Heating/Cooling; the Rest of the Day Free Floating

Simulation Period	Type of Light Control	Time Step (min)	Load(KW)		Energy (kwhrs)	
			Heating	Cooling	Heating	Cooling
Dec 11-15	Manual	5	565	0	16819	0
	Manual	10	438	0	16160	0
	Manual	20	426	0	14943	0
	Manual	30	416	0	13788	0
	Manual	60	368	0	10737	0
	Localised	60	400	0	13258	0
	Photo, on/off	60	400	0	11147	0
Mar 13-17	Manual	60	283	-3.1	8206	-5.2
	Localised	60	300	0	8858	0
June 19-23	Manual	5	263	-50	2345	-437
	Manual	10	156	-54	2146	-517
	Manual	20	134	-63	1802	-700
	Manual	30	120	-74	1531	-918
	Manual	60	98	-111	975	-1824
	Localised	60	101	-108	992	-1942
	Photo, on/off	60	101	-104	928	-2180
Oct 9-13	Manual	60	152	-71	2526	-607
	Localised	60	152	-25	4188	-50

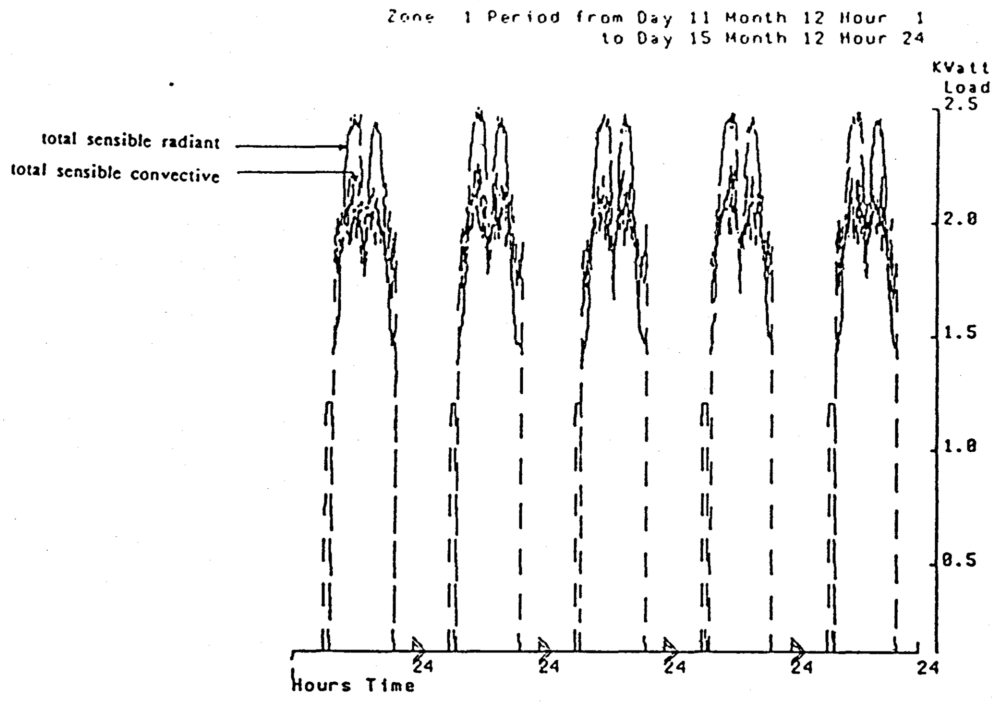


Fig. 7.1

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Manual and the

Daylight Factor 2% (5 minute time steps)

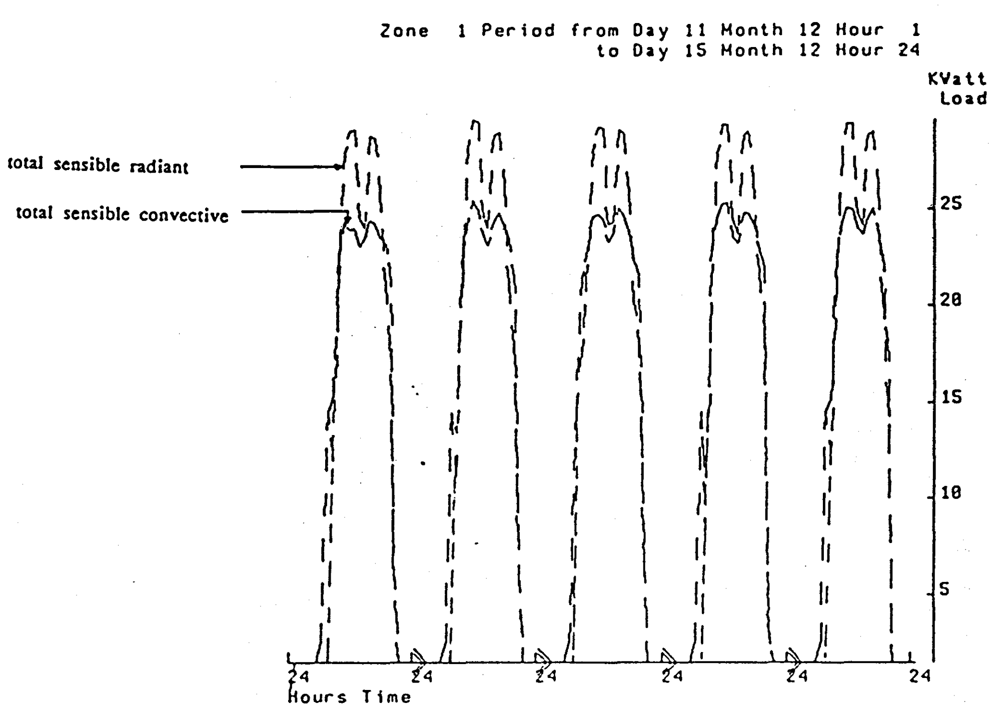


Fig. 7.2

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Manual and the

Daylight Factor 2% (60 minute time steps)

1 for an hourly time step.

(b) When each zone of the building was assumed to be controlled by localised lighting control. The predictions of building energy requirements have been carried out for an hourly time step. Figure 7.3 shows the stochastic profiles of zone 1 in an hourly time step for the winter week. It is obvious that because the lighting control was localised, the total zone internal heat gain was less than the manual light control (see Figure 7.2). It would be expected therefore that the maximum heating load and the heating energy requirements are higher for the localised lighting control. See Table 7.1.

(c) When each zone of the building was assumed to be controlled by photoelectric on/of control. The predictions of building energy requirements have been carried out for an hourly time step and for the winter and summer weeks only. Figure 7.4 shows the profiles of zone 1 of the building for an hourly time step and for the winter week also. The results of heating/cooling loads and the building energy requirements of both simulated weeks are listed in Table 7.1. Again the values of heating load and heating energy requirements show that the lighting use controlled by a photoelectric control was less than the manual lighting control.

(2) When the daylight factor of each zone was assumed as 0.5% (a low value), the following loads and energy predictions have been carried out for an hourly time step for the winter and summer weeks only. The results are listed in Table 7.2

(a) When the zone was assumed to be controlled by manual lighting control. The stochastic profile of the internal heat gain of zone 1 is shown in Figure 7.5 for the winter week.

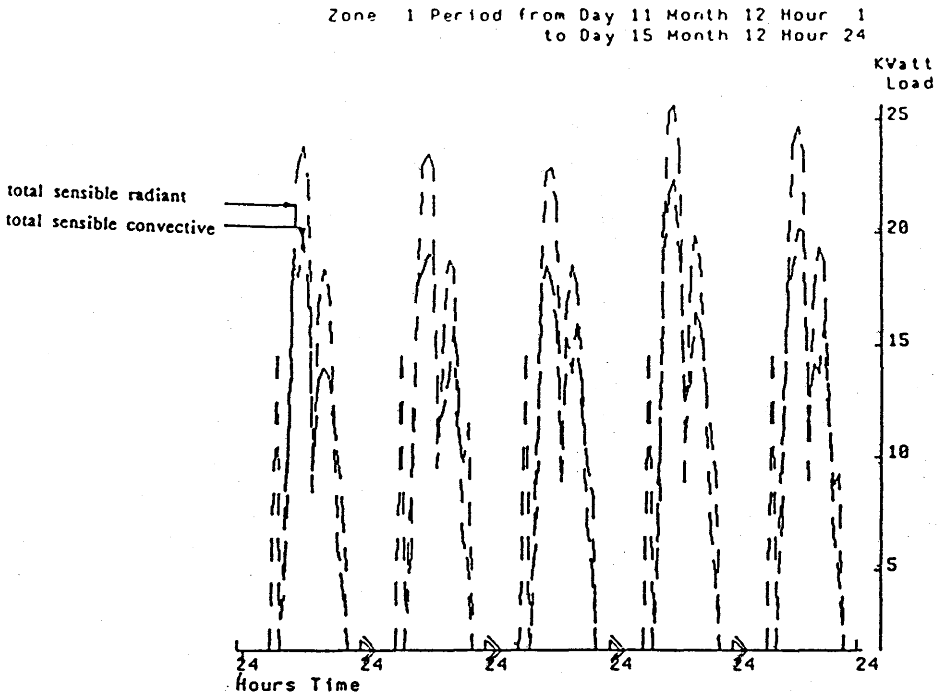


Fig. 7.3

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Localised and the

Daylight Factor 2% (60 minute time steps)

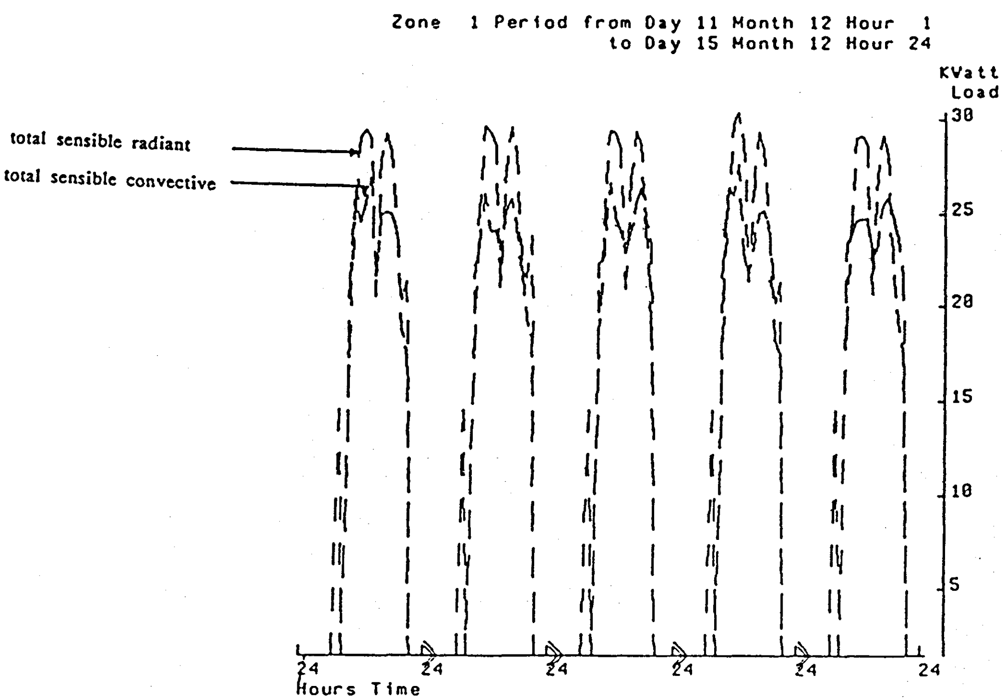


Fig. 7.4

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Photoelectric

On/Off and theDaylight Factor 2% (60 minute time steps)

TABLE 7.2

Load and Energy Prediction Using the Stochastic Profiles of Internal Heat Gain. The Daylight Factor of the Zones is 0.5% and the Building Control Strategy as Mentioned in Table 7.1.

Simulation Period	Type of light Control	Time Step (min)	Load (Kw)		Energy (kwhrs)	
			Heating	Cooling	Heating	Cooling
Dec 11-15	Manual	60	383	0	11039	0
	Localised	60	400	0	11181	0
June 19-23	Manual	60	102	-143	809	-3275
	Localised	60	102	-165	705	-4392

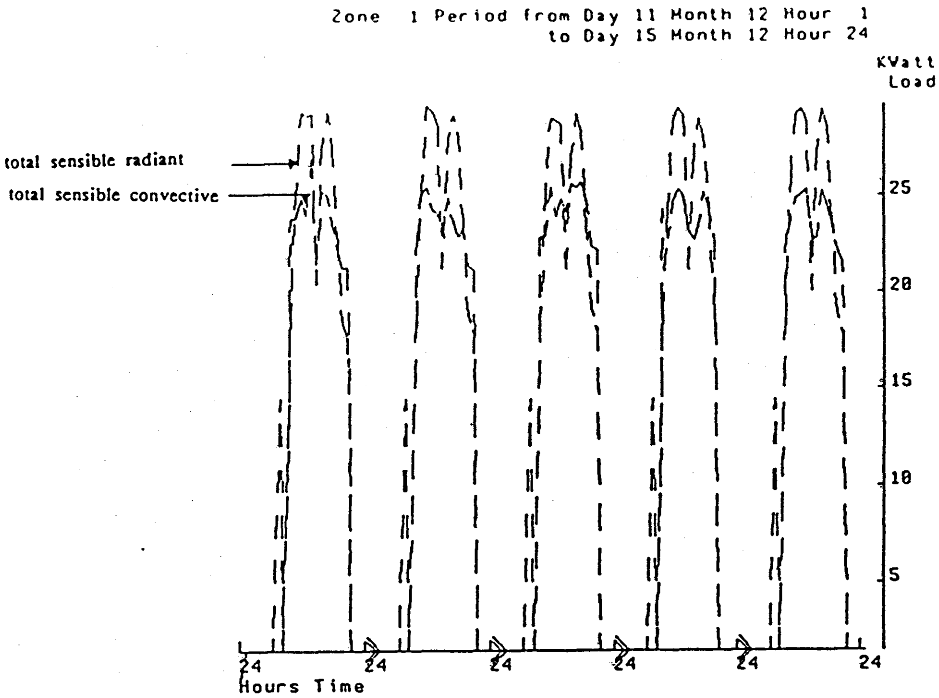


Fig. 7.5

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Manual and the

Daylight Factor 0.5% (60 minute time steps)

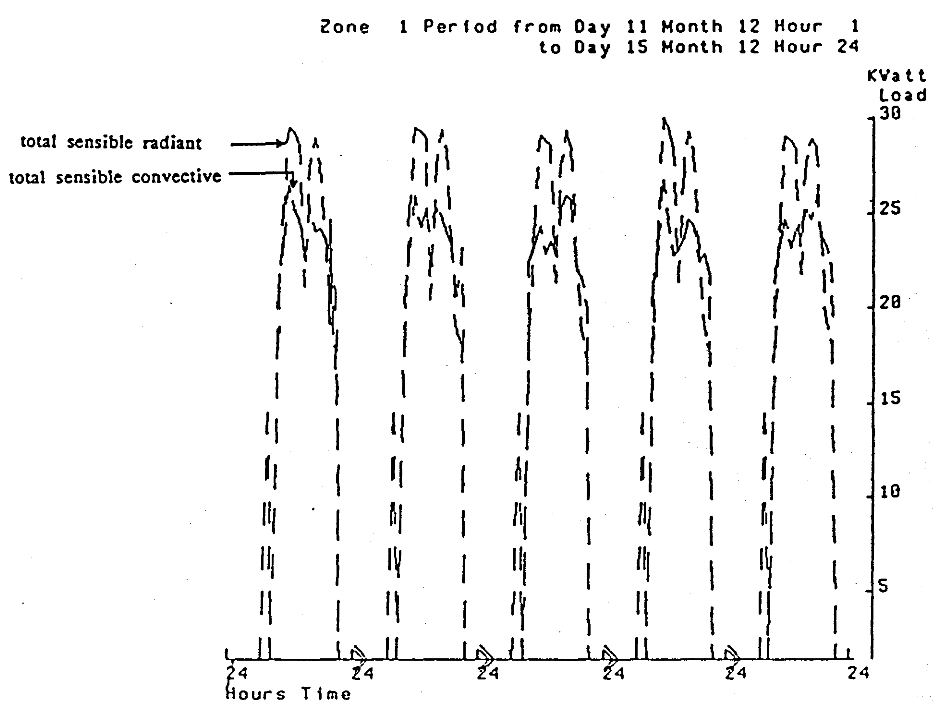


Fig. 7.6

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Photoelectric

On/Off and the Daylight Factor 0.5% (60 minute time steps)

(b) When the zone was controlled by an on/off photoelectric control. The profile of zone 1 is shown in Figure 7.6 for the winter week also.

These two types of light control were chosen as an example to check the effect of the minimum daylight factor on the building energy requirements since both types of control are dependent on this value.

To compare all the results of building loads and energies obtained by using the stochastic internal heat gain profiles with those for the constant profiles the predictions of the building heating/cooling loads and the energy requirements have been carried out for the constant profile (9.00 - 17.00 hrs) with a control strategy of preheating from 7.00 to 9.00 hrs and normal heating/cooling from 9.00 to 17.00 hrs. Figure 7.7 shows the hourly total sensible convective, sensible radiant internal heat gain of each zone of the building. For smaller time steps the hourly values were averaged by ESP (eg. for 5 minute time steps, the hourly values were divided by 12, and so on). For the winter and summer weeks the predictions were carried out for 5, 10, 20, 30 and 60 minute time steps, while for spring and autumn weeks it was carried out for an hourly time step only. All the results of the predictions are listed in Table 7.3. The above case (the constant profile 9.00 - 17.00 hrs with the mentioned control strategy) was assumed to be the common practice for estimating the building internal heat gain profile. However, because the control strategy adopted for the stochastic profile assumed that the preheating was between 5.00 and 7.00 hrs and the normal heating/cooling was between 7.00 and 19.00 hours, it was felt that the difference between the predictions of loads and energies of the constant and the stochastic profiles would be related not only to the differences in the energy provided by the internal heat gains, but also to the differences of the control strategy (a difference of 2 hours in the early morning ie 5.00 - 7.00 hrs, and 2 hours in the evening ie. 17.00 - 19.00 hrs). Hence the

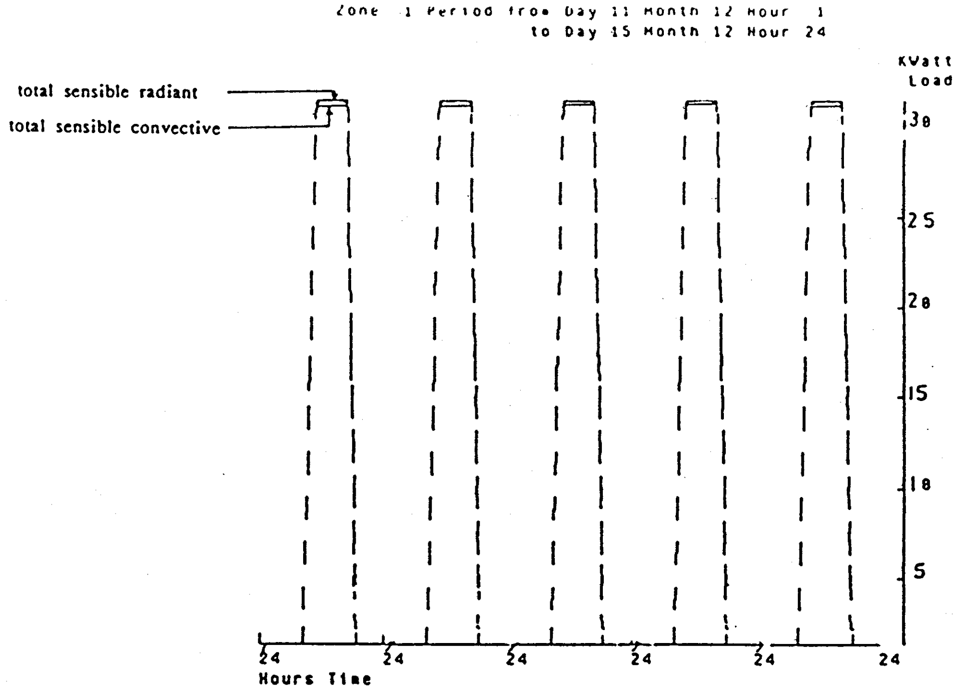


Fig. 7.7

The Simple Hypothetical Profile of

Internal Heat Gain (9-17) Hrs.

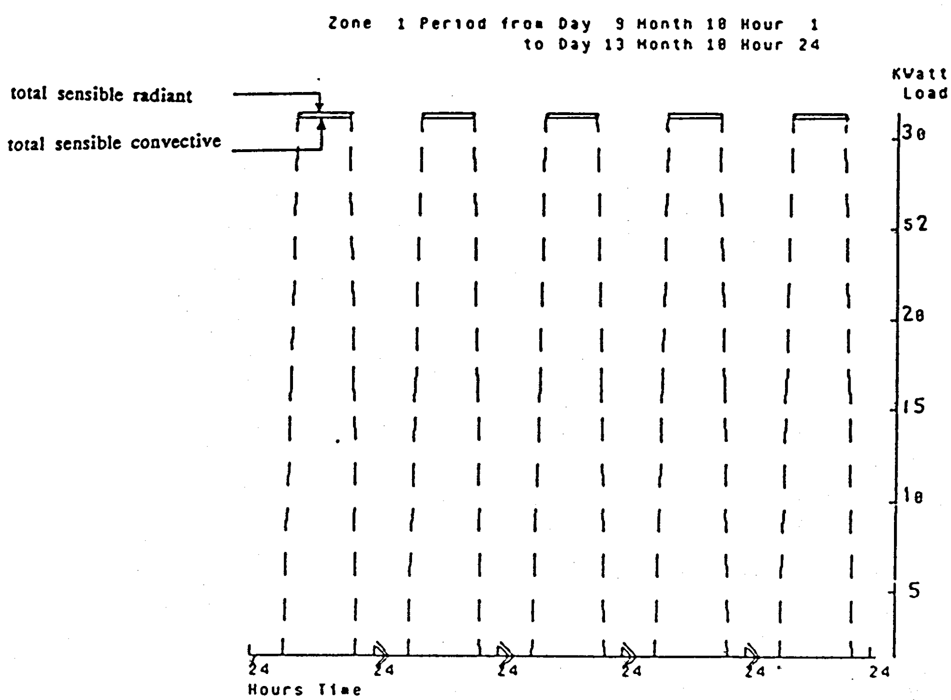


Fig. 7.8

The Simple Hypothetical Profile of

Internal Heat Gain (7-19) Hrs.

TABLE 7.3

Load and Energy Predictions Using the Constant Profile
(9 - 17) hrs of Internal Heat Gain.
The Building Control Strategy:
7.00 to 9.00 hrs as pre-heating
9.00 to 17.00 hrs normal heating/cooling
The rest of the day was free floating.

Simulation Period	Time Step (min)	Load(Kw)		Energy (kwhrs)	
		Heating	Cooling	Heating	Cooling
Dec 11-15	5	554	-63	4153	-529
	10	430	-61	4020	-503
	20	416	-58	3848	-468
	30	412	-56	3759	-439
	60	338	-50	3724	-387
Mar 13-17	60	248	-138	1865	-2716
June 19-23	5	169	-314	351	-8897
	10	92	-313	308	-8887
	20	72	-311	239	-8862
	30	61	-309	187	-8852
	60	49	-304	110	-8831
Oct 9-13	60	121	178	776	-4803

same control strategy (5.00 to 7.00 hrs preheating and 7.00 to 19.00 hrs normal heating/cooling) was adopted for the constant profile 9.00 - 17.00 hrs to predict the building energy requirements. The results of this case are listed in Table 7.4 for each week. A comparison between the results of the constant profile (9.00 - 17.00) listed in Table 7.3 and the results listed in Table 7.4 show that the effect of the control strategy is significant.

Since the stochastic profiles were representing the internal heat gain for the flexible working hours and these profiles were generally observed between 7.00 and 19.00 hrs with little difference from one day to another, it became important to investigate the significance of the differences of the loads and energies when the constant profiles were considered as 7.00 - 19.00 hrs (see Figure 7.8) using the same control strategy in both. The results of this case are listed in Table 7.5 for each week. Flowchart 7.2 summarizes all the cases considered above. The results of the building heat/cooling loads and the energy requirements obtained by using the stochastic profiles and the constant profiles will be analyzed and compared in the following section.

TABLE 7.4

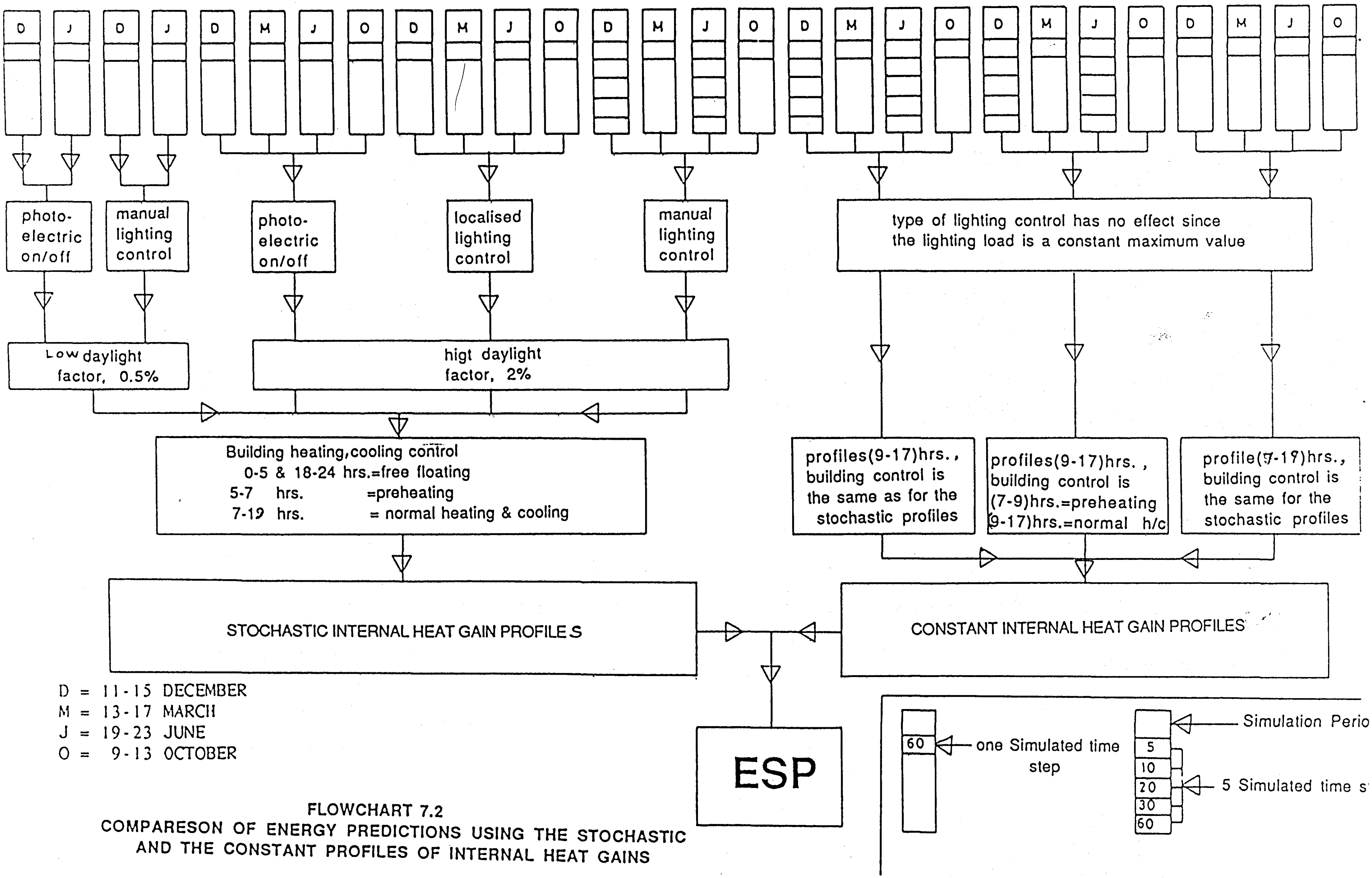
Load and Energy Predictions Using the Constant Profile
(9 - 17) hrs of Internal Heat Gain.
The Building Control Strategy Same as for the
Stochastic Profile (see Table 7.1)

Simulation Period	Time Step (min)	Load(K'w)		Energy (kwhrs)	
		Heating	Cooling	Heating	Cooling
Dec 11-15	5	548	-87	7443	-980
	10	425	-86	7337	-950
	20	414	-83	7168	-898
	30	409	-81	7078	-854
	60	396	-77	7059	-766
Mar 13-17	60	319	-149	4681	-3171
June 19-23	5	245	-319	993	-9395
	10	144	-318	943	-9377
	20	124	-318	892	-9356
	30	114	-314	808	-9339
	60	96	-191	682	-9310
Oct 9-13	60	151	-191	2130	-5010

TABLE 7.5

Load and Energy Predictions Using the Constant Profile
(7 - 19) hrs of Internal Heat Gain.
The Building Control Strategy:
5.00 to 7.00 hrs as pre-heating
7.00 to 19.00 hrs normal heating/cooling
The rest of the day was free floating.

Simulation Period	Time Step (min)	Load (Kw)		Energy (kwhrs)	
		Heating	Cooling	Heating	Cooling
Dec 11-15	60	335	-94	3412	-1772
Mar 13-17	60	273	-163	2029	-5065
June 19-23	60	96	-327	360	-13790
Oct 9-13	60	124	-220	714	-8106



D = 11-15 DECEMBER
M = 13-17 MARCH
J = 19-23 JUNE
O = 9-13 OCTOBER

FLOWCHART 7.2
COMPARESON OF ENERGY PREDICTIONS USING THE STOCHASTIC AND THE CONSTANT PROFILES OF INTERNAL HEAT GAINS

7.3 RESULTS ANALYSIS AND DISCUSSION:

From the results listed in Table 7.1 through 7.5, the following cases could be discussed and analyzed.

(1) The effect of using the stochastic model and comparison of energy predictions with those obtained from the simple constant profiles.

(2) The effect of using different time steps.

(3) The effect of the type of lighting control on the total building energy requirements.

(4) The effect of the daylight factor on the total building energy requirements.

These four cases are discussed as follows:

(1) The effect of using the stochastic model and comparison of energy predictions with those obtained from the simple constant profiles:

Flowchart 7.2 shows clearly the compared cases where for each type of profile, the building heating/cooling control strategy is shown. In this flowchart it is important to notice the times when the heating/cooling plant were assumed to start and to end (building control strategy) because this aspect had a significant effect on the estimation of building energy requirements.

Three cases of comparison are discussed and analyzed. These cases are as follows:

(a) Consider the results of load and energy predictions listed in Table 7.1 for the stochastic profile and the results listed in Table 7.3 for the constant profile (9 - 17 hrs) (bearing in mind that the control strategies in both are different). It can be seen that the building heating loads and the heating energy requirements predicted by using the stochastic profiles for whatever type of lighting control are higher than those of the constant profile 09.00 – 17.00 hrs. The maximum heating load was for example 9% higher in December when the building was controlled by manual lighting control, and the heating energy requirements were approximately

2.9 times greater for the total simulation period. These differences were taken for the hourly time step simulations. These large differences are related not only to differences in the energy provided by the internal heat sources, but also to the differences in the heating control strategy. Referring to Figure 7.2 and 7.7 it can be seen that the estimation of the total energy provided by the internal heat gain of the stochastic model was less than that of the simple profile (09.00 – 17.00 hrs). From the building control strategy it can be seen that the number of hours that the heating system was running for the case of the stochastic profile was higher than that of the constant profile (2 hours more in the early morning (05.00 – 07.00 hrs), and 2 hours more in the afternoon (17.00 – 19.00 hrs)). Figures 7.9 and 7.10 show the load profile in relation to the internal /external temperature of zone 1 for the stochastic profile with manual lighting control and the constant profile respectively. These two figures show that the difference in the steepness of the load profile during the occupation period was related to the energy provided by the internal heat sources. The load profiles in these figures also show the difference in the running times of the heating system. On the other hand, the cooling loads and the cooling energy requirements predicted by using the constant profiles were generally much greater than those of the stochastic profiles. For example, in June, the maximum cooling load was 2.8 times greater, and the cooling energy requirement was approximately 4 times greater. The reason could be related mainly to the high energy provided by the internal heat sources which was assumed to follow a constant maximum value during the occupation period. Figure 7.11 and 7.12 show the load profile in June for the stochastic and constant profiles respectively. From Figure 7.12 it can be seen that the steepness of the cooling load profile is very high, and the daily use of the cooling system is high also. That could be related to the constant maximum heat gain from the internal heat sources. Hence the cooling energy requirements

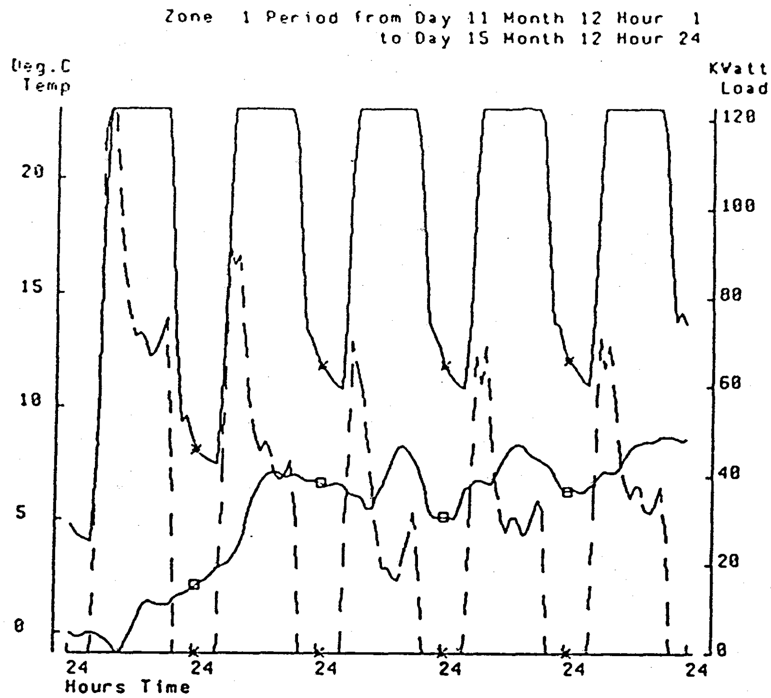


Fig. 7.9

Plant Load and Internal/External Air

Temperature Profiles of Zone 1 When the

Stochastic Profile Was Used and the Lighting

Control Was Manual

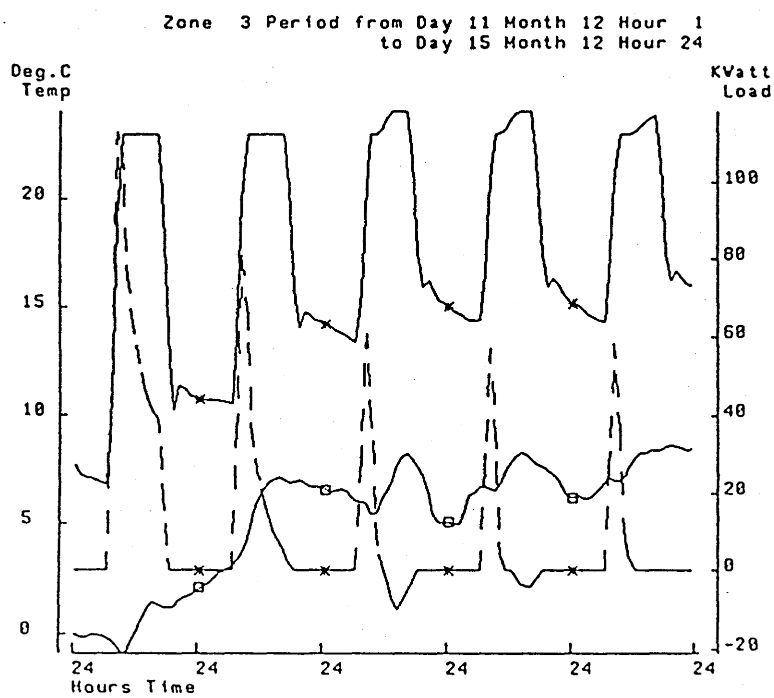


Fig. 7.10

Plant Load and Internal/External Air

Temperature Profiles of Zone 1 When the

Constant Profile (9-17) Hrs. Was Used

Legend

-----*----- Plant Load Profile

——*—— Internal Air Temperature Profil

——□—— External Air Temperature Profil

+ve Heating

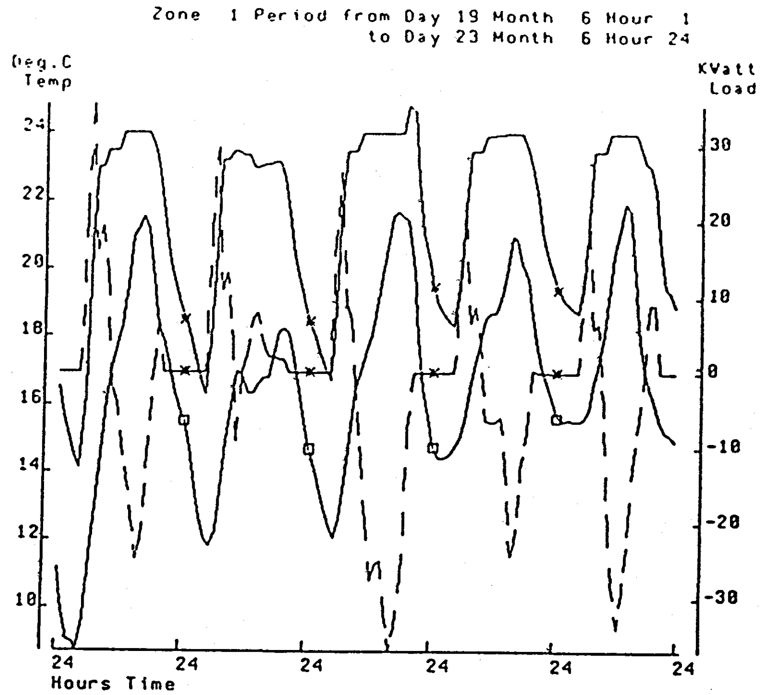


Fig. 7.11

Plant Load and Internal/External Air

Temperature Profiles of Zone 1 When the

Stochastic Profile Was Used and the Lighting

Control Was Manual

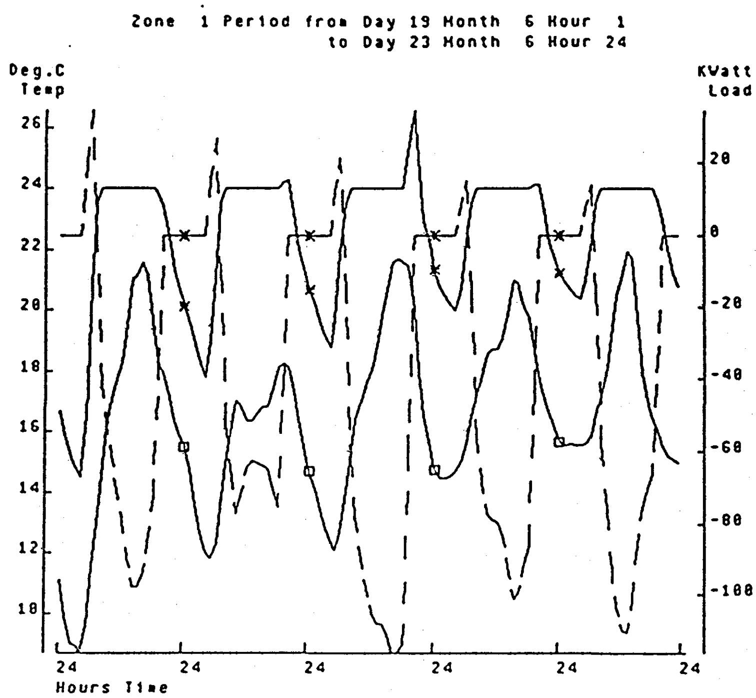


Fig. 7.12

Plant Load and Internal/External Air

Temperature Profiles of Zone 1 When the

Constant Profile (9-17) Hrs. Was Used

Legend
-----*----- Plant Load Profile
——*—— Internal Air Temperature Profi
——□—— External Air Temperature Profi
+ve Heating

were also high.

In summary, the differences between the predictions of load and energies of the stochastic and constant profile (09.00 – 17.00 hrs) were high because they were not only related to the difference in the amount of energy provided by the internal heat sources but also to the difference in the building heating/cooling control strategy.

By calculating the building's total heating/cooling energy requirements (kWhrs) predicted by using the stochastic profiles with localised lighting control for the four simulated weeks (20 days) (Table 7.1 for the hourly time step), it was found that the total building energy requirements were 26% higher than that of the constant profile (Table 7.3). The difference was calculated also when the light control was manual, and found that the total energy requirements were 7% higher than the constant profiles.

(b) In order to relate the differences of the predictions of loads and energies for the stochastic and the constant profiles (09.00 – 17.00 hrs) to the differences in the amount of the energy provided by the internal heat sources only, the building control strategy was equalized in both profiles. This meant that the running of the heating/cooling plant was for the same number of hours in both profiles (05.00 – 07.00 hrs as preheating and 07.00 – 19.00 hrs as normal heating/cooling). Table 7.4 shows the results of load and energy predictions for the constant profile (09.00 – 17.00 hrs) with the above control strategy. A comparison between the result of this table and the result in Table 7.3 shows that the difference in the control strategy applied on the constant profile (09.00 – 17.00 hrs) caused significant differences in the predicted loads and energies. For example, in winter the new control strategy caused a 90% increase in the building energy requirements.

A comparison between the results of Table 7.4 and Table 7.1 of the stochastic profiles shows that the differences between the heating energy requirements are less than case (a) above. For example, in December, the heating energy requirements of the stochastic profile was 52% higher. On the other hand, because the number of running hours of the cooling system was high in the case of the constant profiles, the cooling energy requirements increased in June, for example, about 5% than the previous control strategy. (See Tables 7.4 and 7.3 for the hourly time step).

In summary, because the total energy provided by the internal heat sources predicted by the stochastic model was lower than that of the constant profile (09.00 – 17.00 hrs), the heating energy requirements especially in winter were higher, and the cooling energy requirements, especially in summer, were much lower.

By calculating the total heating/cooling energy requirement (kWhrs) predicted by the constant profile for the four simulated weeks (20 days) (Table 7.4 for the hourly time step), it was found that the total building energy requirements for the four simulated weeks was 32% higher than that of the stochastic profile with a manual lighting control (Table 7.1). The difference was also calculated when the light control was localised and it was found that the energy required for the constant profile was 12% higher.

It was indicated earlier that the occupation period of the flexible working hours was generally observed between 07.00 and 19.00 hrs with little variation from one day to another. The significance of the differences in the building loads and energies have been investigated when the occupation period was assumed as 07.00 – 19.00 hrs for the constant profiles and the control strategy was the same as for the stochastic profiles. The results of this case are listed in Table 7.5. Rather than comparing the results of this table with the results of the stochastic profiles (Table 7.1), it will be compared with Table 7.4 (the constant profile 09.00 – 17.00 hrs), hence this comparison will reveal implicitly the significance of the differences between the constant profile (07.00 – 19.00

hrs) and the stochastic profiles. From Table 7.5, because the occupation period has increased 4 hrs more than the 09.00 – 17.00 hrs profiles, (b) above, the thermal energy stored in the fabric of the building from the internal heat sources has increased also. Hence the number of heating hours has been reduced, while the number of cooling hours has increased. (Check with Table 7.4). The heating energy requirements in December, for example, have decreased to half, while in June, the cooling energy requirements have increased by 43%.

By calculating the total heating/cooling energy requirement (kWhrs) for the four simulated weeks (20 days) of Table 7.5 for the hourly time steps, it was found that the total building energy requirements during the four weeks was 42% higher than that of the stochastic profile with manual lighting control (Table 7.1) and 20% higher when the lighting control was localised.

Generally speaking, from the analysis of the three cases mentioned above, it seems that for the same control strategy whatever was the assumption for the constant hypothetical profiles of internal heat gains, the differences in the building heating/cooling loads were significant when compared with the results obtained by using the stochastic model.

(2) The effect of using diff10rnt time steps:

It was mentioned in Section 2.3 that ESP performs the energy balance for each zone of the building at each <u>time step</u> [1.1.2]. Hence if the simulation time step was 5 minutes, then the energy balance for each zone therefore was performed simultaineously and repeatedly at each 5 minute time step of the day. It is important to indicate that when the simulation time step was small (say, 5 minutes) it meant that it was required from the heating or cooling plant to meet the total building load in 5 minutes. Since this time is very small, it would be expected therefore, that the power required to achieve the process is very high. For example, consider the performance of the heating plant in a winter day at the first simulation time step. In this time step it is required from the plant to warm up the space to offset all the transient gains through the building fabric and structure and reach the design condition (23° C) in 5 minutes. Certainly the power requirement in this case is much higher when compared with the hourly time step. This explains why the heating/cooling load values were getting higher when the simulation time step was smaller. (See Tables 7.1, 7.3, 7.4). Hence it became invalid to compare the differences between the building load and energy predictions in different time steps (eg. the 5 minutes time steps with the hourly time steps and so on).

(3) The effect of the type of lighting control on the total building energy requirements:

Before analyzing the effect of the type of lighting control (lighting use) on the building energy requirements, it is important to indicate that the predictions of the building internal heat gains may vary slightly from one running of the stochastic program to another because of the stochastic process (random number). Hence if one input variable (eg. the type of light control) has been changed between two runs of the model, then the differences in the results of the two runs will not only be related to the change of this variable (the light control in this case) but also to the stochastic process. However, this should have a minor effect on the comparisons of the results. To have an indication about the effect of choosing different lighting controls, the results listed in Table 7.1 could be discussed. It can be seen that the heating energy requirements of the building were high (in all simulated weeks) when the lighting was controlled by localized switches. For the winter week, for example, it was 23% higher than the case when the lighting control was manual and 19% higher than the photoelectric on/off control. This could be explained by referring to the stochastic profiles shown in Figure 7.2 for the manual lighting control, Figure 7.3 for the localised, and Figure 7.4

for the photoelectric on/off. It is obvious that the total energy provided by internal heat sources is less when the lighting control was localised (for more details, refer to Section 5.7.). In summer, (see Table 7.1 for June) the cooling energy requirement when the lighting control was localised is 6% higher than the case when the lighting control was manual. Figure 7.13 shows that the lighting controlled by manual switches was off during the 5 simulated days because the probability of switching was very low due to the high daylight level in June. Hence the heat emission was only from the lighting during the cleaning activity (06.00 – 07.00 hrs), the people and the equipment. For the localized lighting control Figure 7.14 shows that because the background lighting was assumed to be on during the occupation period, the total building internal heat emission was higher, hence the cooling load and the cooling energy requirements were therefore higher. For the photoelectric lighting control on/off, Figure 7.15 shows the lighting was in full use during the early morning and the evening hours because the minimum working plane illuminance was less than the design illuminance. Therefore the total energy provided by the internal heat sources was higher and the cooling energy requirement was also higher. The cooling energy predicted by using photoelectric on/off control was 12% higher than the localised lighting control and 19% higher than the manual control.

In summary the type of lighting control had a significant effect on the total building heating and cooling requirements.

(4) The effect of the daylight factor on the total building energy requirements:

Table 7.1 listed the results of energy predictions when the daylight factor was assumed 2%. Table 7.2 listed the results of energy predictions when the daylight factor was assumed as 0.5%. Consider the case in winter (December). It can be seen that the difference between the predictions of building heating energy requirements (ie.due to the difference in the

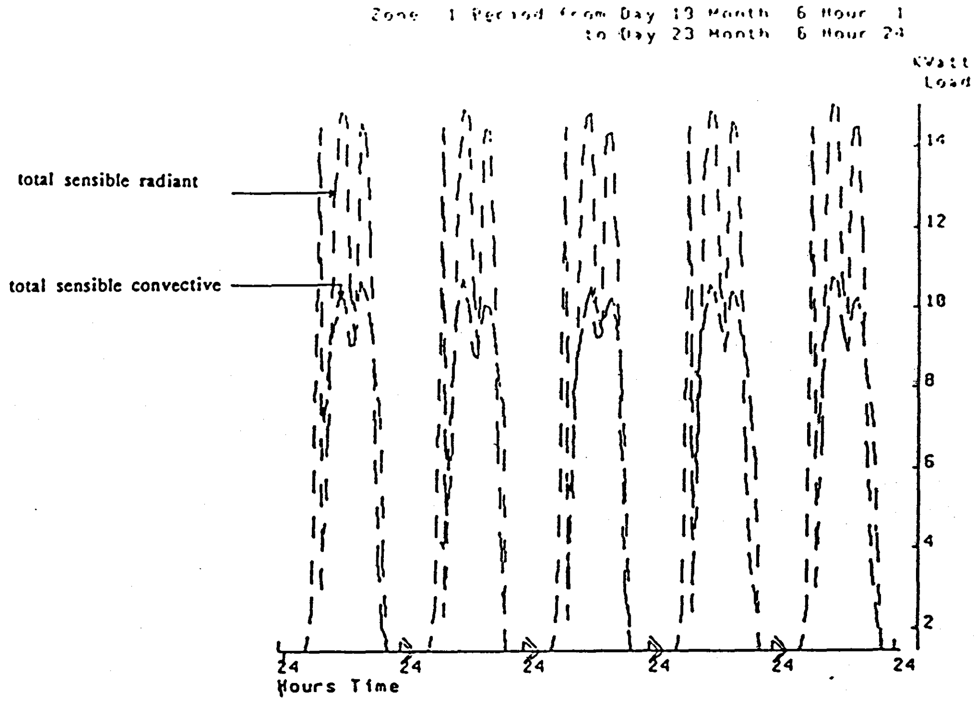


Fig. 7.13

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Manual and the

Daylight Factor 2% (60minute time steps)

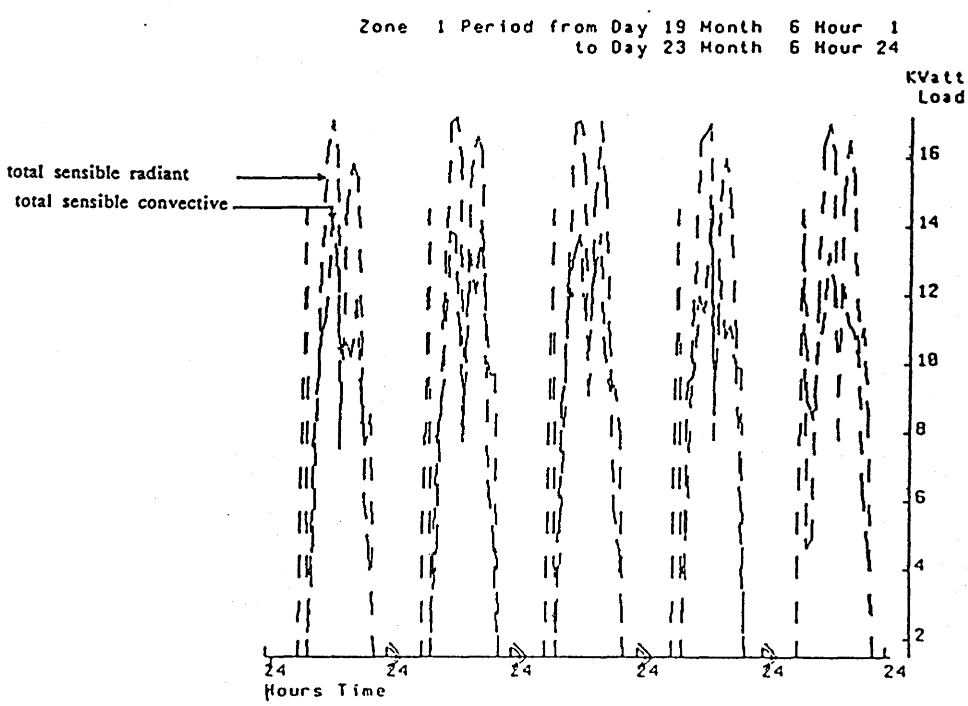


Fig. 7.14

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Localised and the

Daylight Factor 2% (60 minute time steps)

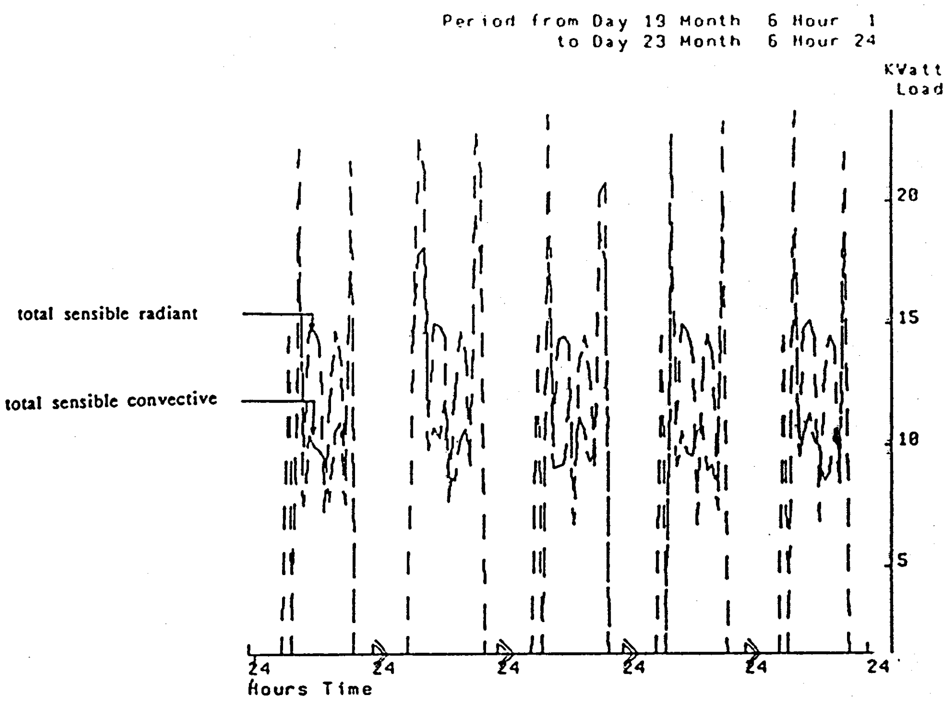


Fig. 7.15

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Photoelectric

On/Off and theDaylight Factor 2% (60 minute time steps)

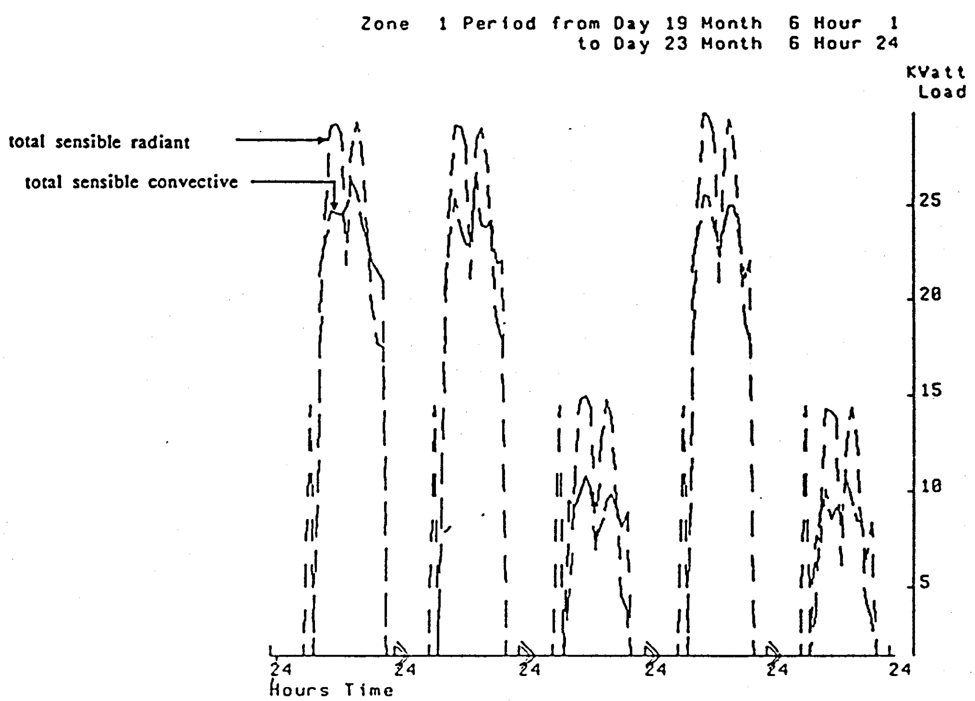


Fig. 7.16

The Stochastic Internal Heat Gain Profile

When the Lighting Control was Manual and the

Daylight Factor 0.5% (60 minute time steps)

daylight factor value) when the lighting control was manual or photoelectric on/off is very small (a difference of 2.5%). That was because the lighting was fully on in both values of daylight factor since the simulated week was December (minimum daylight availability). This small difference was due to the stochastic process between the two runs. However, in summer it can be seen that because the daylight factor was small (0.5%) the probability of switching on the light was high and the light use was also high. Figure 7.16 shows when the daylight factor considered as 0.5%, the lighting was in full use for 3 days and was off only for 2 days and the profile in those 2 days representing the heat emission from people and equipment and lighting during the cleaning activity (06.00 – 07.00 hrs) only. But Figure 7.13 shows when the daylight factor was 2%, the light was fully off during the occupation period of the 5 days because the probability of switching was very low and the profile was representing the heat emission from lighting during the cleaning activity (06.00 – 07.00 hrs) and from people and equipment. Hence the cooling energy requirements were therefore higher for the 0.5% daylight factor (80% higher), see Table 7.2 and 7.1 in June and for the hourly time steps.
For the photoelectric control, the lighting use in winter is approximately the same for both values of daylight factors. But in summer the lighting use was higher when the daylight factor was 0.5%, (for details see Section 5.7.). Hence the cooling energy requirements were approximately twice.

In summary, the daylight factor had a significant effect on the building total cooling energy requirements and a minor effect on the heating energy requirements.

8. *GENERAL CONCLUSIONS AND RECOMMENDATIONS*

This project has illustrated techniques for simulating building occupancy patterns, artificial lighting use and equipment use for the purpose of estimating the internal heat gains. It is suggested that the stochastic model which was presented as a computer progam offers the designer the flexibility and the possibility of predicting accurately internal heat gain profiles for different design situations and therefore to obtain a better estimation of the heating/cooling loads and the total energy requirements. The analysis of building energy requirements (Section 7.3) has shown that the differences between the heating and cooling energy requirements predicted by ESP using the constant and the stochastic profiles of internal heat gains were significant. The total energy released by the internal heat sources as represented by the stochastic profiles was generally lower than that of the constant profiles. For that reason the heating energy requirement especially in winter was higher, but the cooling energy requirement especially in summer was much lower when the more realistic profiles were used. From the comparison between the total (heating and cooling) energy requirements it was found that the constant profiles resulted in an overestimation of 12% to 42%. This range was dependent upon the type of lighting control within the stochastic model. With the localised lighting control, the overestimation resulting from the use of the constant profile (9−17) hrs was 12% and 20% for the (7−19) hrs profile. For manual lighting control the use of these constant profiles resulted in overestimations of 32% and 42% respectively. These differences demonstrate that the use of the constant profiles of internal heat gains leads to an inaccurate estimate of the overall heating and cooling loads and energy requirements. Moreover, these differences indicate that consideration of the type of lighting control is important in estimating the actual heat gain from the lighting. Therefore, the stochastic model should be used instead of the present deterministic approaches for example as subroutines inside ESP. Programs, such as ESP are used to compare the energy costs of alternative designs of buildings. The difference in these energy costs are likely to be less than 10% in most cases and could well be insignificant compared to the errors attributable to the inaccurate estimates of internal gains which have been evaluated.

It is worth mentioning that the practical applications of the stochastic modelling is limited by the absence of suitable input data. In particular, the following are required:

(a) occupancy data for buildings other than offices (eg. factories, warehouses, etc). This would enabale the model to be applied in different situations.

(b) the probabilistic data for the availability of daylight (as shown in Table 5.2). This would enable a detailed model to be developed to predict the daylight according to the probability of occurance for a certain location, and then to be extended to cover different locations.

Defining the building occupancy patterns is not only important for the purposes intended for this study, but also could offer the possibility of defining the number of the people in the building for behavioural studies.

Examples are:

(a) The interaction of the building occupants with the thermal environment and controls (thermostat adjustments, door and window openings, etc). Predictions of these aspects of behaviour would help to study more accurately the building heating/cooling plant performance and provide means of modifying the existing building controls.

(b) The estimation of the air quality and the fresh air requirements for the space. The occupancy pattern identification would help to assess accurately the amount of fresh air according to the number of people in a space. Hence a better estimation of the hygienic loads would be provided.

Generally , stochastic techniques could be adopted to cover a wide range of thermal applications and to develop stochastic modelling programs as front–end programs for building thermal modelling programs such as ESP. It is recommended that the range of models considered would include:

(1) Simulations of climatic data which affect fabric and ventilation heat gains and losses. The climatic data would be simulated for certain locations (eg. Kew, south of England). Available meteorlogical data will enable the frequency distributions to be obtained (eg. for the external air temperature) for the values occurring at a certain hour, hence a suitable stochastic technique could be adopted to simulate likely climatic sequences. This of course would include the seasonal variations. It is important to mention that the more extensive the data collected (ie. for long periods of time, eg. 10 years) the more realistic will be the predictions.

(2) Having simulated the climatic data, direct calculation of fabric and ventilation heat gains and losses could be made for studies of plant performance. Alternatively, gains and losses could be simulated directly for specific constructions in specific locations. They could then be extended to cover a wide range of structures and locations. The statistical data required to develop the simulation model would involve experimental work to record what happens in real life.

(3) Simulation of loads generated by service systems. This involves the simulations of loads on the plant due to the service such as hot water, steam, compressed air, etc. The frequency distributions for these loads could be obtained from monitoring studies. Hence the simulation of these loads would be based on the probabilities of occurance. The energy required by the plant to meet the likely loads could then be assessed with due regard paid to any seasonal variations.

APPENDIX

TABLE A1

THE OBSERVED FREQUENCY OF THE ARRIVAL TIME OF THE VISITORS, WHERE THE TOTAL NO. OF OBSERVATIONS IS 1921.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
6.7500	3	0.0051611	0.0015610
6.9170	10	0.0052050	0.0067670
7.0830	3	0.0051610	0.0083280
7.2500	15	0.0078080	0.0161370
7.4170	44	0.0229040	0.0390420
7.5830	14	0.0072870	0.0463300
7.7500	121	0.0629880	0.1093180
7.9170	151	0.0786040	0.1879220
8.0840	41	0.0213430	0.2092660
8.2500	78	0.0406030	0.2498690
8.4170	25	0.0130140	0.2628830
8.5840	23	0.0119720	0.2748560
8.7500	110	0.0572610	0.3321180
8.9170	201	0.1046330	0.4367510
9.0840	75	0.0390421	0.4757930
9.2500	69	0.0359180	0.5117120
9.4170	65	0.0338360	0.5455490
9.5840	25	0.0130140	0.5585630
9.7510	27	0.0140550	0.5726180
9.9170	44	0.0229040	0.5955230
10.0840	29	0.0150960	0.6106190
10.2510	30	0.0156160	0.6262360
10.4170	29	0.0150960	0.6413320
10.5840	29	0.0150960	0.6564280
10.7510	25	0.0130140	0.6694420
10.9170	40	0.0208220	0.6902650
11.0840	31	0.0161370	0.7064020
11.2510	30	0.0156160	0.7220190
11.4180	13	0.0067670	0.7287870
11.5840	19	0.0089000	0.7386770
11.7510	14	0.0072870	0.7459650
11.9180	17	0.0088490	0.7548150
12.0840	9	0.0046850	0.7595000
12.2510	22	0.0114520	0.7709520
12.4180	20	0.0104110	0.7813630
12.5840	21	0.0109318	0.7922950
12.7510	10	0.0052050	0.7975010
12.9180	21	0.0109318	0.8084330
13.0850	10	0.0052050	0.8136380
13.2510	8	0.0041640	0.8178030
13.4180	19	0.0098900	0.8276930
13.5850	12	0.0062460	0.8339400
13.7510	14	0.0072870	0.8412280
13.9180	33	0.0171780	0.8584070
14.0850	27	0.0140550	0.8724620
14.2510	25	0.0130140	0.8854760
14.4180	24	0.0124930	0.8979690
14.5850	20	0.0141120	0.9083810
14.7520	31	0.0161370	0.9245180
14.9180	11	0.0057260	0.9302440
15.0850	23	0.0119729	0.9422170
15.2520	17	0.0084950	0.9510670
15.4180	21	0.0109318	0.9619980
15.5850	12	0.0062460	0.9682450
15.7520	8	0.0041640	0.9724100
15.9180	20	0.0104112	0.9828210
16.0850	9	0.0046850	0.9875060
16.2520	6	0.0031230	0.9906290
16.4190	4	0.0020822	0.9927120
16.5850	9	0.0046850	0.9973970
16.7520	3	0.0015610	0.9989590
16.9190	2	0.0010410	1.0000000

TABLE A2

THE OBSERVED DURATIONS OF STAY (GROUP 1). THE NO. OF OBSERVATIONS IS 839.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
0.0830	7	0.0083430	0.0083430
0.2500	3	0.0035700	0.0119180
0.4170	2	0.0023800	0.0143020
0.5830	7	0.0083430	0.0226460
0.7500	4	0.0047600	0.0274130
0.9170	4	0.0047600	0.0321810
1.0830	0	0.0000000	0.0321810
1.2500	8	0.0095350	0.0417160
1.4170	2	0.0023800	0.0441000
1.5840	1	0.0011900	0.0452920
1.7500	6	0.0017500	0.0524430
1.9170	3	0.0035700	0.0560190
2.0840	0	0.0000000	0.0560190
2.2500	1	0.0011900	0.0572100
2.4170	0	0.0000000	0.0572100
2.5840	0	0.0000000	0.0572100
2.7500	1	0.0011900	0.0584020
2.9170	3	0.0035700	0.0619780
3.0840	2	0.0023800	0.0643620
3.2510	3	0.0035700	0.0679380
3.4170	4	0.0047600	0.0727050
3.5840	3	0.0035700	0.0762810
3.7510	1	0.0011900	0.0774730
3.9170	5	0.0059500	0.0834320
4.0840	1	0.0011900	0.0846240
4.2510	0	0.0000000	0.0846240
4.4170	0	0.0000000	0.0846240
4.5840	8	0.0095350	0.0941590
4.7510	2	0.0082380	0.0965430
4.9180	1	0.0011900	0.0977350
5.0840	1	0.0011900	0.0989270
5.2510	5	0.0059500	0.1048860
5.4180	0	0.0000000	0.1048860
5.5840	6	0.0071500	0.1120380
5.7510	1	0.0011900	0.1132300
5.9180	2	0.0023800	0.1156130
6.0840	3	0.0035700	0.1191890
6.2510	3	0.0035700	0.1227650
6.4180	2	0.0023800	0.1251480
6.5850	12	0.0143020	0.1394510
6.7510	3	0.0035700	0.1430270
6.9180	5	0.0059500	0.1489860
7.0850	9	0.0107270	0.1597130
7.2500	23	0.0274130	0.1871270
7.4180	18	0.0214540	0.2085810
7.5850	17	0.0202600	0.2288430
7.7510	21	0.2502000	0.2538730
7.9180	49	0.5844000	0.3122760
8.0850	120	0.1430200	0.4553030
8.2520	93	0.1108000	0.5661500
8.4180	69	0.0822400	0.6483900
8.5850	52	0.0619700	0.7103690
8.7520	67	0.0798500	0.7902260
8.9180	73	0.0870080	0.8772340
9.0850	53	0.0631700	0.9404050
9.2520	19	0.0226400	0.9630510
9.4180	8	0.0095300	0.9725860
9.5850	3	0.0035700	0.9761620
9.7520	2	0.0023800	0.9785450
9.9190	13	0.0154900	0.9940400
10.0830	4	0.0047600	0.9988080
10.2520	0	0.0000000	0.9988080
10.4190	0	0.0000000	0.9988080
10.5850	1	0.0011900	0.9999990

TABLE A3

THE OBSERVED DURATIONS OF STAY (GROUP 2). THE NO. OF OBSERVATIONS IS 405.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
0.0830	10	0.0246910	0.0246910
0.2500	39	0.0962900	0.1209870
0.4170	28	0.0691635	0.1901230
0.5830	14	0.0345600	0.2246910
0.7500	31	0.0765400	0.3012340
0.9170	16	0.0395060	0.3407400
1.0830	9	0.0222222	0.3629620
1.2500	21	0.0518510	0.4148140
1.4170	14	0.0345670	0.4493820
1.5840	5	0.0123450	0.4617280
1.7500	13	0.0320980	0.4938270
1.9170	3	0.0074000	0.5012340
2.0840	7	0.0172830	0.5185180
2.2500	5	0.0123400	0.5308640
2.4170	9	0.0222222	0.5530860
2.5840	2	0.0049380	0.5580240
2.7500	1	0.0024690	0.5604930
2.9170	0	0.0000000	0.5604930
3.0840	10	0.0246910	0.5851850
3.2510	0	0.0000000	0.5851850
3.4170	2	0.0049380	0.5901230
3.5840	3	0.0074000	0.5975300
3.7510	6	0.0148140	0.6123450
3.9170	10	0.0246910	0.6370370
4.0840	0	0.0000000	0.6370370
4.2510	0	0.0000000	0.6370370
4.4170	1	0.0024690	0.6395060
4.5840	1	0.0024690	0.6419750
4.7510	1	0.0024690	0.6444440
4.9180	2	0.0049380	0.6493820
5.0840	4	0.0098760	0.6592590
5.2510	1	0.0024690	0.6617280
5.4180	0	0.0000000	0.6617280
5.5840	1	0.0024690	0.6641970
5.7510	0	0.0000000	0.6641970
5.9180	6	0.0148140	0.6790120
6.0840	3	0.0074000	0.6864190
6.2510	3	0.0074000	0.6938270
6.4180	9	0.0222220	0.7160490
6.5850	5	0.0123400	0.7283950
6.7510	4	0.0098760	0.7382710
6.9180	3	0.0074000	0.7456790
7.0850	6	0.0148140	0.7604930
7.2510	14	0.0345670	0.7950610
7.4180	15	0.0370370	0.8320980
7.5850	6	0.0148140	0.8469130
7.7510	16	0.0395060	0.8864190
7.9180	32	0.0790120	0.9654320
8.0850	9	0.0222222	0.9876540
8.2520	2	0.0049380	0.9925920
8.4180	3	0.0074000	0.9999990

TABLE A4

THE OBSERVED DURATIONS OF STAY (GROUP 3). THE NO. OF OBSERVATIONS IS 215.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
0.0830	12	0.0558130	0.0558130
0.2500	21	0.0976740	0.1534880
0.4170	30	0.1395300	0.2930230
0.5830	10	0.0465100	0.3395340
0.7500	25	0.1162790	0.4558130
0.9170	23	0.1069760	0.5627900
1.0830	11	0.0511620	0.6139530
1.2500	17	0.0790690	0.6930230
1.4170	4	0.0186040	0.7116270
1.5840	2	0.0093020	0.7209300
1.7500	7	0.0325580	0.7534880
1.9170	4	0.0186040	0.7720930
2.0840	6	0.0279060	0.8000000
2.2500	0	0.0000000	0.8000000
2.4170	1	0.0046510	0.8046510
2.5840	3	0.0139530	0.8186040
2.7500	2	0.0093020	0.8279060
2.9170	6	0.0279000	0.8558130
3.0840	0	0.0000000	0.8558130
3.2510	4	0.0186040	0.8744180
3.4170	1	0.0046510	0.8790690
3.5840	1	0.0046510	0.8837200
3.7510	1	0.0046510	0.8883720
3.9170	1	0.0046510	0.8930230
4.0840	1	0.0046510	0.8976740
4.2510	0	0.0000000	0.8976740
4.4170	1	0.0046510	0.9023250
4.5840	1	0.0046510	0.9069760
4.7510	0	0.0000000	0.9069760
4.9180	4	0.0186040	0.9255810
5.0830	6	0.0279060	0.9534880
5.2510	1	0.0046510	0.9581390
5.4180	2	0.0093020	0.9674410
5.5840	2	0.0093020	0.9767440
5.7510	0	0.0000000	0.9767440
5.9180	1	0.0046510	0.9813950
6.0840	1	0.0046510	0.9860460
6.2510	0	0.0000000	0.9860460
6.4180	0	0.0000000	0.9860460
6.5850	0	0.0000000	0.9860460
6.7510	1	0.0046510	0.9906970
6.9180	1	0.0046510	0.9953480
7.0850	0	0.0000000	0.9953480
7.2500	0	0.0000000	0.9953480
7.4180	0	0.0000000	0.9953480
7.5850	0	0.0000000	0.9953480
7.7510	1	0.0046510	0.9999990

TABLE A5

THE OBSERVED DURATIONS OF STAY (GROUP 4). THE NO. OF OBSERVATIONS IS 242.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
0.0830	16	0.0661150	0.0661150
0.2500	20	0.0826400	0.1487600
0.4170	17	0.0702470	0.2190080
0.5830	14	0.0578510	0.2768590
0.7500	19	0.0785120	0.3553710
0.9170	19	0.0785120	0.4338840
1.0830	9	0.0371900	0.4710740
1.2500	10	0.0413220	0.5123960
1.4170	14	0.0578510	0.5702470
1.5840	7	0.0289250	0.5991730
1.7500	10	0.0413220	0.6404950
1.9170	5	0.0206611	0.6611570
2.0840	9	0.0371900	0.6983470
2.2500	5	0.0206611	0.7190080
2.4170	7	0.0289250	0.7479330
2.5840	6	0.0247930	0.7727270
2.7500	2	0.0082640	0.7809910
2.9170	8	0.0330570	0.8140490
3.0840	9	0.0371900	0.8512390
3.2510	4	0.0165289	0.8677680
3.4170	8	0.0330570	0.9008260
3.5840	2	0.0082640	0.9090900
3.7510	1	0.0041320	0.9132230
3.9170	2	0.0082640	0.9214870
4.0840	5	0.0206611	0.9421480
4.2510	3	0.0123966	0.9545450
4.4170	6	0.0247930	0.9793380
4.5840	1	0.0041320	0.9834710
4.7510	1	0.0041320	0.9876030
4.9180	0.	0.0000000	0.9876030
5.0840	0.	0.0000000	0.9876030
5.2510	0	0.0000000	0.9876030
5.4180	3.	0.0123960	0.9999990

TABLE A6

THE OBSERVED DURATIONS OF STAY (GROUP 5). THE NO. OF OBSERVATIONS IS 220.

TIME	OBSERVED NO.	PROBABILITY	CUMULATIVE PROBABILITY (c.d.f)
0.0830	28	0.1272720	0.1272720
0.2500	43	0.1954540	0.3227270
0.4170	35	0.1590900	0.4818180
0.5830	9	0.0409090	0.5227270
0.7500	28	0.1272720	0.6500000
0.9170	26	0.1181800	0.7681810
1.0830	9	0.0409090	0.8090900
1.2500	12	0.0545400	0.8636360
1.4170	13	0.0590900	0.9227270
1.5840	3	0.0136360	0.9363630
1.7500	5	0.0227270	0.9590900
1.9170	2	0.0090900	0.9681810
2.0840	2	0.0090900	0.9772720
2.2500	1	0.0045450	0.9818180
2.4170	2	0.0090900	0.9909090
2.5840	0	0.0000000	0.9909090
2.7500	0	0.0000000	0.9909090
2.9170	0	0.0000000	0.9909090
3.0840	0	0.0000000	0.9909090
3.2510	0	0.0000000	0.9909090
3.4170	0	0.0000000	0.9909090
3.5840	1	0.0045450	0.9954540
3.7510	1	0.0045450	0.9999990